

AN ABSTRACT OF THE THESIS OF

Janel L. Banks for the degree of Master of Science in Fisheries Science presented on November 2, 2005.

Title: Influences of Clearcut Logging on Macroinvertebrates in Perennial and Intermittent Headwaters of the Central Oregon Coast Range

Abstract approved:

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This research was designed to broaden the understanding of how timber-harvest affects aquatic macroinvertebrates in perennial and intermittent headwater streams. This study compared emergent and benthic macroinvertebrate assemblages from 20 headwater streams in the central Oregon Coast Range that varied by harvest condition and flow duration. Through comparison of the community and functional characteristics of the macroinvertebrates in similar streams under different harvest conditions, logging impacts on adult and immature aquatic macroinvertebrates in perennial and intermittent streams were assessed.

Adult insects emerging from the 20 study streams were collected using emergence traps set for four weeks in a 40-meter reach during three sampling periods: August-September 2003, October-November 2003, and April-May 2004. Adult aquatic insects were identified to genus and family taxonomic levels and results were expressed as number of individuals emerging per m² per day. Benthic samples were taken from each reach in May 2004, insects and non-insects were identified to various taxonomic levels, and results were expressed as number of individuals per m². Ten streams were located in catchments that were clearcut to the stream bank no more than a year before sampling began; three of these streams were intermittent and seven were perennial. Intermittent streams were summer-dry and retained surface-water for a minimum of eight months during the year, while perennial streams had surface flow year-round. The other ten streams (four intermittent and six perennial) were located in forested catchments that have not been logged for at least 34 years. The physical habitat of each stream reach was assessed in August 2003.

Regardless of flow-duration or season, more aquatic insects emerged from streams in logged catchments. The emergence rate of Diptera, predominantly Chironomidae, was especially high from clearcut sites. More Trichoptera also emerged from clearcut sites. Ephemeroptera and Plecoptera did not emerge at rates that varied by logging condition. Plecoptera had higher emergence from intermittent than perennial sites in spring. Taxa richness was higher at clearcut sites, driven primarily by rare taxa encountered in less than 5 of the 10 clearcut sites. Emergent insect functional feeding group composition was affected by harvest condition with collector-filterers emerging at higher rates from clearcut sites.

Examination of community patterns through nonmetric multidimensional scaling (NMS) ordination analyses indicated that emergent aquatic macroinvertebrate assemblages differ by season and by harvest condition. The duration of stream flow did not strongly influence adult assemblages. Channel dimensions (active channel and bankfull width) and catchment area were correlated with ordination-axes, but were not different between logged and forested sites. The amount of riparian cover (canopy, understory, and groundcover), stand age, slash, and stream cover were all considerably different between logged and forested sites and were highly influential on emergent assemblages. Substrate size was also influential on adult assemblages. Mean water temperature in summer, fall, and spring was highly correlated with seasonal variation in assemblages.

Regardless of harvest-condition, intermittent streams had higher overall benthic macroinvertebrate density. Trichoptera had higher densities at intermittent sites than perennial sites, while Diptera, Plecoptera, and non-insects had similar densities between categories of flow duration and harvest condition. Benthic macroinvertebrate functional composition was also affected by flow-duration, with collector-filterers, collector-gatherers, and predators occurring at higher densities at intermittent sites than perennial sites. The densities of scrapers and shredders did not differ between classes of flow duration or harvest condition. The majority of taxa (72%) were common to both perennial and intermittent sites; however, taxa richness was lower at intermittent sites.

NMS-ordination analyses of the benthic macroinvertebrates showed that community patterns differed by harvest condition within the perennial flow-duration class. Benthic communities of intermittent streams did not differ between harvest conditions. Channel dimensions (active channel and bankfull width), mean substrate diameter, percent stream-cover, mean water temperature, elevation, and percent small riparian trees influenced benthic community assemblages. The majority of perennial-clearcut sites had macroinvertebrate community patterns more similar to intermittent-forested and intermittent-clearcut streams than to perennial-forested sites. The two perennial-clearcut sites that did not have benthic assemblages similar to the other five perennial-clearcut sites had larger diameter substrate, higher elevation, larger catchment area, and cooler mean water temperature than other perennial-clearcut sites.

This study provides evidence that Oregon's current timber harvesting practices impact macroinvertebrate assemblages of perennial and intermittent headwaters in the Central Oregon Coast Range within a year following harvest. When the studied streams were clearcut to the streambank, there was increased emergence of adult macroinvertebrates, principally midges, at clearcut sites. Benthic assemblages differed primarily between intermittent and perennial flow-duration. However, within flow-classes, assemblages of benthic aquatic macroinvertebrates in perennial streams were impacted by clearcut logging to a higher degree than intermittent streams. Perennial-clearcut streams had different benthic assemblages from perennial-mature streams and perennial-clearcut streams with coarser substrate and cooler temperatures. Intermittent streams, which generally experience fewer flushing events and accumulate finer substrates than perennial streams, may be affected to a lesser degree by any sedimentation caused by logging activity. Correlations of emergent and benthic macroinvertebrate communities with the measured environmental gradients are suggestive that reduced canopy cover and substrate composition are major influential factors.

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Influences of Clearcut Logging on Macroinvertebrates in Perennial and Intermittent Headwaters
of the Central Oregon Coast Range

by
Janel L. Banks

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Janel L. Banks, Author

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Drs. Alan Herlihy and Judith Li assisted in the interpretation of data, the design, and the writing of both Chapter 2 and 3. Dr. Alan Herlihy also frequently assisted with data collection and data analyses.

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INFLUENCES OF CLEARCUT LOGGING ON MACROINVERTEBRATES IN PERENNIAL AND
INTERMITTENT HEADWATERS OF THE CENTRAL OREGON COAST RANGE

Chapter 1

Introduction

Janel L. Banks

By delivering water, sediment, and organic material, headwater streams feeding downstream reaches serve important ecological and biological functions (Sidle et al. 2000; Meyer and Wallace 2001; Gomi et al. 2001; Wipfli and Gregovich 2002). Headwaters include four types of topographic units: hillslopes drainages generally with no channelized flow, unchannelized hollows of zero-order basins, ephemeral or temporary channels emerging from zero-order basins, and first- and second-order stream channels (Gomi et al. 2002). Leopold et al. (1964) estimated that perennial first- and second-order streams alone represent 95% of stream channels and approximately 73% of stream channel length in the United States. These are conservative estimates of headwater contributions as there are many more perennial streams than appear on standard 1:24,000 US Geological Survey maps; moreover streams without perennial flow were excluded (Leopold 1994; Meyer and Wallace 2001).

In a single catchment, headwater streams can make up nearly 85% of channel length, and they have the tightest linkages between water and land (Sidle et al. 2000; Meyer and Wallace 2001; Gomi et al. 2002). Both their position in the drainage network and their spatial extent make them highly influential on downstream reaches. Small streams are either perennial or seasonally intermittent, depending on location in the watershed, annual climatic cycles, and modifications of hydrological patterns by human activities (Harr et al. 1975; Whiles and Wallace 1995; Mackay 1996; Price et al. 2003). These small streams are vulnerable to anthropogenic alterations of the landscape affecting the catchment, riparian zone, or stream channel. However, most headwater streams do not support fish and have been understudied, particularly in the Pacific Northwest where decision-makers and managers focus on salmonids (Moore and Richardson 2003). Whether perennial or intermittent, headwater streams are affected by timber harvest if riparian buffers cannot maintain natural conditions (Newbold et al. 1980; Brown et al. 1997; Delucchi and Peckarsy 1989; Dieterich and Anderson 2000; Cole et al. 2003). Current Forest Practice Rules in Oregon do not require any riparian buffers on small, non-fish-bearing streams (ODF 2004), leaving these stream communities particularly vulnerable to physical, chemical, and biological impacts of timber harvesting. Reductions of forest cover that alter headwater dynamics can

change linkages to downstream reaches (Wipfli and Gregovich 2002), and between terrestrial and aquatic systems (England and Rosemond 2004).

Macroinvertebrate communities in small streams are strongly influenced by edge interactions with adjacent terrestrial habitats. Where small streams are heavily shaded in forested catchments, fauna depend on a food base derived from allochthonous organic matter. The River Continuum Concept predicts shredders and collectors, who depend on riparian-derived food sources in headwaters, would dominate functional feeding group composition in these small streams (Vannote et al. 1980). When riparian trees are removed, the solar radiation that reaches the stream bottom increases and terrestrial canopy inputs decrease (Stockner and Shortreed 1976). In streams that are not nutrient limited, algal communities increase productivity under augmented insolation, potentially shifting the energy base from allochthonous sources to autochthonous periphyton production (Murphy and Hall 1981; Shortreed and Stockner 1983; Noel et al. 1986; Fuchs et al. 2003). Because of its low C:N ratio, periphyton provides a higher quality food than autochthonous organic matter (Boyd 1973; Anderson and Cummins 1979) and is available to other trophic levels both as live algae and as organic detritus. Macroinvertebrate assemblages respond to increased primary productivity in a variety of ways, including higher densities and an increase in scraper density (Hawkins et al. 1982; Murphy et al. 1981; Newbold et al. 1980; Noel et al. 1986).

After logging ceases, riparian vegetation will recover, the canopy will close, and the stream will become shaded again. Hence, the energy base of the stream will shift back to allochthonous sources over time, and the macroinvertebrate community composition will usually return to pre-logging assemblages (Stone and Wallace 1998). Because leaves from early successional plants are broken down more quickly in the stream and provide higher food quality than leaves from older established stands, shredders may be highest when plant species, such as alder, dominate the riparian (Piccolo and Wipfli 2002; Stone and Wallace 1998). As the forest canopy recovers, early successional plants are shaded out and the spike in shredder densities usually diminishes (Stone and Wallace 1998). In British Columbia, Canada, Fuchs et al. (2003)

documented no difference in the macroinvertebrate density and biomass, feeding guild density and biomass, and chlorophyll a biomass when they compared streams that flowed through old-growth forests with streams in forests logged 20-25 years ago. At Coweeta Hydrological Laboratory in North Carolina, Stone and Wallace (1998) observed a similar recovery from clearcutting over a 16-year study.

Seasonal fluctuations in flow can expand or decrease the stream habitat available for aquatic macroinvertebrates. Headwater streams, at the top of the drainage network, often cease flowing when the water table falls below the streambed. Intermittent streams characteristically dry regularly, usually during periods of low rainfall such as summer. Invertebrates dwelling in intermittent streams must be suited to survive yearly dry-channel conditions (Williams 1996). Behavioral and physical adaptations to survive annual drought include avoidance through diapause, emergence, or relocation to better habitat (burrowing into the hyporheic zone; seeking surface pools; downstream migration; etc.). Evidence is growing that intermittent streams harbor a subset of fauna found in perennial streams as well as unique taxa of which little is currently known (Dieterich 1992; Williams 1996; Feminella 1996; Muchow and Richardson 1999). When land management activities alter the riparian zone, macroinvertebrates well suited to survival and colonization of intermittent streams may be negatively impacted if patterns in drought disturbance are altered.

Evaluations of logging-impacts have traditionally investigated effects on perennial fish-bearing streams, but not on intermittent streams, non-fish-bearing reaches, or their associated macroinvertebrate assemblages. There are current proposals that forest managers should increase protection of small non-fish-bearing streams. Given the extent of the landscape potentially affected by increased protection, small headwater streams have become a research priority (Naiman et al. 1993; Moore and Richardson 2003). In the last decade, interest in these systems and potential effects of timber harvest on them has led to the formation of organizations, such as the Oregon Headwaters Research Cooperative (OHRC). OHRC is a research cooperative supported by a small group of agencies, organizations, and companies with research

goals focused on gaining scientific understanding of the physical and biological processes of headwater stream systems and testing the local and downstream response of headwater streams to a range of forest management practices.

Among many other projects, OHRC funded our two-phase project to organize and augment data on headwater streams in western Oregon. The first phase surveyed available information about perennial headwaters in three forested ecoregions in western Oregon: the Coast Range, the Klamath Mountains, and the Cascades (Herlihy et al. 2005). Macroinvertebrate, fish, physical habitat, and land cover data were compiled for 167 streams with catchment areas less than 10 km². We found no strong relationships between macroinvertebrate communities in these streams with either logging activity, presence/absence of fish, catchment size, or ecoregion. The second phase of the project, represented by this thesis, is an empirical study focused on fewer sites sampled multiple times. The second phase compliments the previous research by expanding existing data with new surveys of headwater streams with catchment areas less than 1 km² under different forest-management designs and precisely defined flow-durations.

The goal of my thesis was to broaden the understanding of how timber-harvest affects aquatic macroinvertebrates in perennial and intermittent headwater streams. The study was focused on streams in the Central Oregon Coast Range. Macroinvertebrates are ubiquitous, sedentary in nature compared to fish, and generally responsive to alteration in physical habitat or water quality. Aquatic insects have two life stages; the larval phase is largely confined to the aquatic environment, while the adult phase is generally terrestrial. In Chapter 2, I analyzed the community and functional patterns of mature aquatic insects captured while emerging from the streams. In Chapter 3, I described community and functional patterns of benthic macroinvertebrate assemblages that include non-insects and immature aquatic insects. Through comparison of the community and functional characteristics of the macroinvertebrates in similar streams under different harvest conditions, logging impacts on adult and immature aquatic macroinvertebrates in perennial and intermittent streams were assessed.

Chapter 2

Influence of Clearcut Logging on Emergent Macroinvertebrates in Headwater Streams of the
Central Oregon Coast Range

Janel L. Banks

ABSTRACT

The main goal of this study was to compare the composition and function of emergent macroinvertebrates between 20 headwater streams in the central Oregon Coast Range that varied by harvest condition and flow duration. We specifically compared macroinvertebrate assemblages and functional feeding group composition among perennial and intermittent headwater streams in recently logged catchments with those in forested basins. Ten streams were located in catchments that were clearcut to the streambank no more than a year before sampling began; three of these streams were intermittent and seven were perennial. Intermittent streams were summer-dry and retained surface-water for a minimum of eight months during the year, while perennial streams had surface flow year-round. The other ten streams (four intermittent and six perennial) were located in forested catchments that have not been logged for at least 34 years. For each of three sampling periods (August-September 2003, October-November 2003, and April-May 2004), emergence traps were set for four weeks in a 40-meter reach at each study stream.

Repeated Measures Two-Way ANOVA was used to examine emergence rates of individual orders and functional feeding groups. Regardless of flow-duration or season, more aquatic insects emerged from streams in logged catchments. The emergence rate of Diptera, predominantly Chironomidae, was especially high from clearcut sites. More Trichoptera also emerged from clearcut sites. Ephemeroptera and Plecoptera did not emerge at rates that varied by logging condition. Plecoptera had higher emergence from intermittent sites than perennial sites in the spring. Functional feeding group composition was affected by harvest condition with collector-filterers emerging at higher rates from clearcut sites.

Nonmetric multidimensional scaling (NMS) ordination analyses indicated that emergent aquatic macroinvertebrate assemblages differ by season and by harvest condition. The duration of stream flow did not strongly influence adult assemblages. Channel dimensions (active channel and bankfull width) and catchment area influenced community assemblages, but were not different between logged and forested sites. The amount of riparian cover (canopy, understory,

and groundcover), stand age, logging debris, and stream cover were all considerably different between logged and forested sites and were highly influential on assemblages. Substrate size was also influential on assemblages, with intermittent (logged and forested) and most perennial-clearcut sites having more fines and sands than perennial-forested sites. Mean water temperature in summer, fall, and spring was highly correlated with seasonal variation in assemblages.

Clearcut logging to the streambank impacted the emergent macroinvertebrate assemblages of the studied headwater streams. The primary response was increased abundances at clearcut sites. Taxa richness was slightly higher at logged sites, driven primarily by taxa that were encountered in less than 5 of the 10 clearcut sites. Evenness tended to be lower at clearcut sites than forested sites reflecting higher emergence of a few taxa at logged sites, but this trend was not significant. Diversity measured by Shannon-Weiner did not differ between logged and forested sites. Emergence rates from intermittent streams were primarily affected by harvest-management rather than duration of surface flow.

INTRODUCTION

Headwater streams compose a large proportion of channel length within stream networks and serve important ecological and biological functions by delivering water, sediment, and organic material to downstream reaches (Sidle et al. 2000; Meyer and Wallace 2001; Gomi et al. 2001; Wipfli and Gregovich 2002). Headwater systems include four types of topographic units: hillslopes drainages generally with no channelized flow, unchannelized hollows of zero-order basins, ephemeral or temporary channels emerging from zero-order basins, and first- and second-order stream channels depending on linkages from hillslopes to channels (Gomi et al. 2002). Small streams are either perennial or seasonally intermittent, depending on location in the watershed, annual climatic cycles, and modifications of hydrological patterns by human activities (Harr et al. 1975; Whiles and Wallace 1995; Price et al. 2003). When the streambed is below the water table intermittent streams will flow. During droughts or periods of low rainfall, such as summer, intermittent streams will cease flowing when the level of the water table falls below the streambed. In forested ecosystems, narrow channel widths of headwater streams and overhanging riparian vegetation form tight linkages between the terrestrial and lotic systems (Vannote et al. 1980; Gregory et al. 1991). Macroinvertebrate communities in these small streams are strongly influenced by changes in the riparian vegetation because of their dependence on a food-base derived from allochthonous inputs (Cummins and Klug 1979; Vannote et al. 1980; Hawkins et al. 1982).

Evaluations of logging impacts have traditionally examined fish-bearing perennial streams; far fewer have assessed effects on smaller perennial or intermittent headwater streams. Previous work has shown that the composition and function of macroinvertebrate communities in low-order, continuously flowing streams are influenced by timber harvest. Reduction in canopy from riparian tree removal increases the total available solar radiation that reaches the stream bottom, which can increase algal production, and decreases terrestrial canopy inputs (Stockner and Shortreed 1976; Murphy and Hall 1981; Noel et al. 1986). When riparian areas are logged, the energy base of small streams potentially shifts from allochthonous to autochthonous sources,

affecting community assemblages. Although many studies have documented changes in both substrate composition and water temperature after logging, shift in the food base is the predominant factor affecting macroinvertebrate communities (Hawkins et al. 1982; Murphy et al. 1981; Newbold et al. 1980; Noel et al. 1986; Kedzierski and Smock 2001). Macroinvertebrates respond to the altered food base in a variety of ways, including higher densities and shifts in functional feeding group predominance (Hawkins et al. 1982; Murphy et al. 1981; Newbold et al. 1980; Noel et al. 1986; Cole et al. 2003; Haggerty et al. 2004). In headwater streams with intact riparian canopies shredders and collectors, dependent on riparian-derived food sources, are the dominant feeding guild (Cummins and Klug 1979; Vannote et al. 1980; Price et al. 2003). When autochthonous resources increase, macroinvertebrate communities are expected to transfer from shredder-dominated to scraper-dominated.

Adult macroinvertebrates emerging from headwaters often enter the terrestrial riparian corridor, where they provide resources to streamside communities and serve as important subsidies to terrestrial fauna (Nakano and Murakami 2001). In addition, downstream movement of immature macroinvertebrates through drift can serve as important food resources to downstream fish bearing reaches (Piccolo and Wipfli 2002). Intermittent headwater streams can harbor species that are adept at colonizing recently disturbed or temporary habitat (Progar and Moldenke 2002). Insect communities in these streams could serve as important colonizers to perennial systems disturbed by logging activities.

Tree harvest that impacts macroinvertebrates communities in intermittent stream-sections can potentially alter perennial communities and/or the resilience of stream assemblages (Brown et al. 1997; Progar and Moldenke 2002). Despite the high concentration of headwater channels and their important ecological functions in the Pacific Northwest, only recently have studies looked at the impact of land-management practices on the macroinvertebrate communities of either perennial or intermittent headwater streams (Haggerty et al. 2002; Wipfli and Gregovich 2002; Progar and Moldenke 2002; Cole et al. 2003; Haggerty et al. 2004).

Timber harvest in the Oregon Coastal Mountains of the Pacific Northwest, U.S.A. incorporates a variety of techniques and occurs on both public and private lands throughout the region. The current Forest Practices Act, which establishes forestry guidelines for all properties in Oregon, classify fishless headwater streams as “N” and does not require riparian buffers that can protect small streams from logging impacts (ODF 2004). This leaves the macroinvertebrate communities of N-class streams vulnerable to logging effects. The main goal of this study was to compare the composition and function of emergent macroinvertebrates between streams with different flow durations and harvest conditions. We specifically compared macroinvertebrate assemblages and functional feeding group composition among perennial and intermittent headwater streams in recently logged catchments with those in forested basins.

METHODS

Study Design

This study had a fully crossed two-factor design with two levels of harvest condition (clearcut and unlogged) and of flow duration (perennial and intermittent). Ten of the twenty sites were in basins clearcut within a year prior to the start of sampling. The remaining ten sites had riparian zones with a developed canopy layer and catchments that had not been logged for a minimum of 34 years. Unlogged sites are referred to as “forested” throughout the text. Within each harvest condition grouping, clearcut or forested, the streams were either perennial or dry during the summer months; we refer to the latter as “intermittent”. The study was originally designed with equal replication of five sites for each combination of harvest condition and flow duration. However, flow duration was predicted based on site conditions in spring 2003, prior to the start of sampling in summer 2003 and before stream channels lost surface flow. The final flow characterization was determined as streams either dried out or retained surface flow during summer months. Differences in the predicted and observed flow duration resulted in an unbalanced study-design of three Intermittent-Clearcut (I-CUT), four Intermittent-Forested (I-FOR), seven Perennial-Clearcut (P-CUT), and six Perennial-Forested (P-FOR) sites.

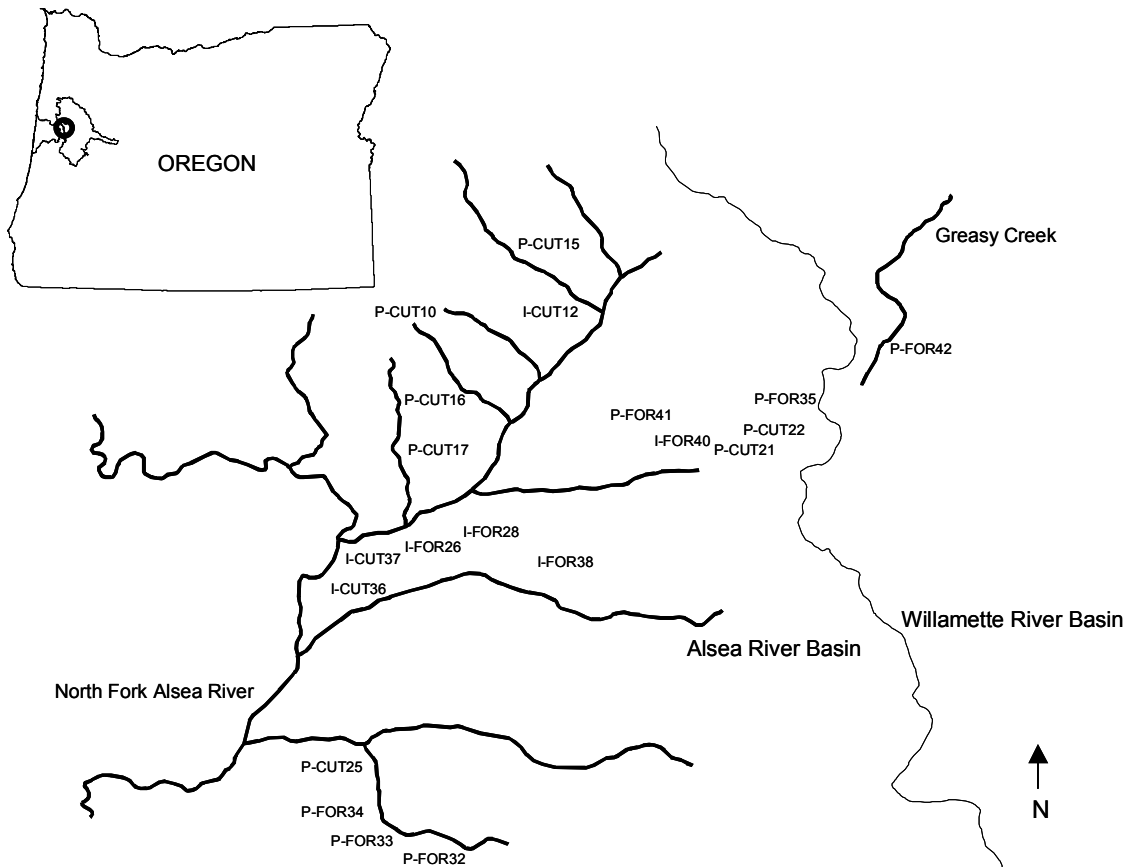


Figure 2.1. Map of the location of the 20 study sites in the Central Oregon Coast Range. Sites are headwaters to the larger tributaries depicted on the map. The alphanumeric code describes the flow duration, harvest condition, and includes a unique number for site identification. Locations marked by I-CUT are intermittent-clearcut sampling sites (n=3), P-CUT are perennial-clearcut (n=7), I-FOR are intermittent-forested (n=4), and P-FOR are perennial-forested (n=6).

Site Selection

All study-streams were zero- to first-order headwater streams located in the Central Oregon Coast Range off of Highway 34 between the towns of Philomath and Alsea. The majority of the streams feed tributaries to the North Fork of the Alsea River. Only one site ultimately drains into the Willamette River and is a headwater of Greasy Creek (Figure 2.1). The Alsea and Willamette Rivers respectively drain the west and east slopes of the Oregon Coast Range. This mountain range runs north to south along the Pacific Ocean with peaks rising 610 to 1,675 meters above sea level. The region has a temperate marine climate with cool, rainy winters and temperate, drier summers. Winter temperatures are generally above freezing at lower elevations

with a mean temperature of 7° C in January, the coldest month of the year. The warmest months are July, August, and September, and usually reach only 9.4° C above January's temperature. Annual rainfall ranges from 1,651-2,286 mm along the coastline and increases with altitude up to 5,080 mm on west-face mountain peaks (Taylor & Hannan 1999).

Through the cooperation of Weyerhaeuser Co. and the Salem District of the Bureau of Land Management (BLM), access to both private and public lands in the Coast Range was possible. A pool of potential sites on Weyerhaeuser timberlands and BLM-managed areas was identified by examination of aerial photographs and topographic maps. Sites were field-checked to determine which candidates had active channel widths less than 4 m, the desired harvest condition, the expected flow-duration, and safe access. The final selection of 20 streams was normalized as much as possible for parental geology, active channel width, and estimated drainage area.

Field Sampling

After a preliminary study with 10 traps set in a 50-meter length of stream, we determined that four traps set in a 40-meter stream section would capture sufficient numbers of adult insects for this study's goals. We then delineated a 40-meter study reach at each of the 20 headwater sites. We collected emergent macroinvertebrates from each stream in summer 2003, fall 2003, and spring 2004, when we also measured stream cover. A modified version of the EPA EMAP protocol for "Quantifying Physical Habitat in Wadeable Streams" was used to characterize the physical habitat of each reach during summer low flows in August 2003 (Kaufmann et al. 1999; Table 2.1). The reach averages of active channel and bankfull widths were calculated from measurements at eleven equidistant transects. We recorded the habitat unit at each transect to calculate the percent of the reach that was fast-water or slow-water habitat type. Fast-water habitat units consisted of falls, cascades, riffles, and rapids, while slow-water habitat units included all pools and glides. At 22 transects we used a modified Wolman pebble-count, recording substrate type (fines, sand, small gravel, big gravel, cobble, boulder, bedrock, or organic) first touched by a finger placed into the water at left-, center-, and right-channel. Stream

gradient was measured for the 40-meter reach with a clinometer. Elevation, catchment area, and stand age were derived from topographic maps and communications with landowners. Riparian vegetation was characterized in August over the entire reach from the stream bank to 10-meters upslope on both left and right sides. We made a visual estimate of vegetation cover at three different heights: ground cover (<0.5 meters), understory (0.5 to 5 m), and canopy (>5 m).

During each season when we deployed emergence traps, we measured stream cover provided by vegetation and topography with a spherical densiometer read at mid-stream in the four cardinal directions and converted to percent cover. Water temperature was recorded every 30-minutes from August 2003 to May 2004 using Onset StowAway TidbiT™ loggers. Each site's mean daily water temperatures were used to calculate both the mean water temperature for the observed nine-months and the mean seasonal water temperature for summer (August-September), fall (October-November), and spring (March-April).

Adult aquatic macroinvertebrates were sampled using emergence traps. Four traps were set for four weeks in all stream reaches during three seasons: summer (August 4 - September 7, 2003), fall (October 16-November 16 2003), and spring (April 5-May 7, 2004). At each site, two of the traps were set within one 20-meter reach section and the additional two traps in the other half of the reach. All sites could not be visited in one day so the start and end of sampling was staggered to accommodate site locations and field conditions. During all seasons we set traps and made collections at the last site no more than four days after the same procedure began at the first site. Each trap covered 0.093 m² of streambed and was draped with no-see-um netting that was anchored along the streambed with in-situ material. A 50:50 mixture of ethylene glycol and water was used in the trap's wells to capture and preserve emergent insects. To prevent sample loss, we collected well contents two weeks after initial trap deployment, reset the traps, and collected for an additional two weeks. Well contents were sieved through a 500 µm screen, transferred into plastic Whirl-Packs®, preserved in 90% ethanol, and returned to the lab for identification.

Table 2.1. Environmental variables derived from physical habitat surveys, topographic maps, and management history compiled for analyses of gradients in community assemblages.

	Unit	Definition
<u>Stream Variables</u>		
Active Channel Width	m	Reach average of the active channel width
Bankfull Width	m	Reach average of the bankfull width
Sand & Fines	%	Substrate in size classes \leq sand (≤ 2 mm)
Small Gravel, Sand, & Fines	%	Substrate in size classes \leq fine gravel (≤ 16 mm)
Coarse Substrate	%	Substrate in size classes $>$ fine gravel (≥ 16 mm)
Organics	%	Substrate composed of wood or organic detritus
Stream Cover	%	Cover from vegetation and topography
Fast-Water Habitat Type	%	Falls+Cascades+Rapids+Riffles
Slow-Water Habitat Type	%	Pools (All Types) + Glides
Seasonal Water Temperature	$^{\circ}$ C	Mean water temperature of summer, fall, or spring
Reach Slope	%	Slope of stream reach
Elevation*	m	Elevation of site
Catchment Area*	ha	Area draining into stream.
<u>Riparian Variables</u>		
Big Trees Canopy	%	Canopy (>5 m high): cover by trees >0.3 DBH
Small Trees Canopy	%	Canopy (>5 m high): cover by trees ≤ 0.3 DBH
Non-Woody Understory	%	Mid-layer (0.5 to 5 high): herbaceous cover
Woody Understory	%	Mid-layer (0.5 to 5 high): woody cover
Non-Woody Ground Cover	%	Ground-layer (<0.5 m): woody cover
Woody Ground Cover	%	Ground-layer (<0.5 m): herbaceous cover
Slash	%	Ground-layer (<0.5 m): logging debris (slash)
Stand Age*	yrs	Years since last logged

* Information derived from topographic maps or landowner communications.

Lab Methods

All adult aquatic macroinvertebrates from each sample were identified. Ephemeroptera and Plecoptera were identified to genus using Merritt and Cummins (1996). Trichoptera were identified to family using Merritt and Cummins (1996) and to genus using a variety of keys (Ross 1956; Denning 1956; Gordon 1974; Blicke 1979; Ninmo 1987; Armitage and Hamilton 1990). Coleoptera were identified to family using Borror et al. (1989). With the exception of empidids, which were identified to genus, Diptera were identified to the family level using McAlpine et al. (1981). Because of the difficulty in identifying chironomids past the family-level determination, we

did not classify these Diptera to a finer taxonomic resolution. We assigned functional feeding groups from Merritt and Cummins (1996) and McAlpine et al. (1981). Identifying Coleoptera and Diptera to family was often sufficient to distinguish the functional feeding group and to determine if the individual's origin was terrestrial or aquatic. The family Chironomidae incorporates many different feeding techniques and could not be assigned a definitive functional group. All insects with either multiple or unknown functional feeding groups in the literature were not considered in further analyses of functional composition.

Data Analysis

Differences in physical habitat variables between harvest conditions and flow durations were examined using Two-Way ANOVAs with p -values <0.01 indicating significant differences between groups. Parameters were either normally distributed or transformed using arcsine square root or \log_{10} .

The tallies for every two-week collection were standardized to emergence rate (individuals/m²/day). For each of the three seasons, we calculated the average daily emergence rate by averaging the daily emergence rate of the two-week periods within the four-week block of continuous sampling. This gave 20 average rates per season and a data set of 60 samples used in all analyses of the macroinvertebrates assemblages and functional composition.

We used Repeated Measures Two-Way ANOVA with Type III Sum of Squares to examine patterns in emergence rates associated with harvest condition and flow duration. A p -value <0.01 indicated significant differences between groups. Repeated-measures analyses allowed us to examine patterns in emergence between classes of harvest and flow while adjusting for repeated sampling at the same sites through time; this maintained the independence of samples required by parametric tests. Using this technique, we analyzed the emergence rate of all insects and of the orders Ephemeroptera, Plecoptera, Trichoptera, and Diptera individually. Very few of the collected insects belonged to different orders than the aforementioned so they were not considered separately. We also analyzed assemblage functional composition using

Repeated Measures ANOVA to examine emergence rates of collector-gatherers, collector-filterers, shredders, scrapers, and predators. No data transformations were necessary.

Taxa richness, evenness, and the Shannon-Wiener index were compared using Repeated Measures Two-Way ANOVA. The Shannon-Wiener index of diversity accounts for both evenness and taxa richness using the formula: $H' = -\sum p_i \ln p_i$ (Magurran 1988). The variable p_i is the proportion of individuals found in the i th taxon and is estimated by n_i / N (the number of individuals in the i th taxon/the total number of individuals). Evenness was calculated by dividing the Shannon-Weiner index by the natural log of taxa richness: $E = H' / \ln S$ (Magurran 1988).

To examine community patterns in macroinvertebrate assemblages, we used Non-metric Multidimensional Scaling (NMS) in PC-ORD, version 4.20 (McCune and Mefford 1999). NMS is a non-parametric ordination method that performs well with community data that are heterogeneous (McCune and Grace 2002). The NMS process begins by deriving a distance matrix composed of the taxonomic dissimilarity (1-similarity) between sites. Sites are then arranged in an ordination in n -dimensional space through the iterative adjustment of between-site distances to represent the ranks of site dissimilarities. We ran all NMS ordinations using a random starting configuration and the Sorenson distance measure to calculate dissimilarity between sites. To reduce the noise in the data so relationships in community assemblages could be discerned more readily, species that occurred in less than 3 of the 60 samples were excluded and the data were $\log_{10}(x+1)$ transformed. Deleting rare species reduced the total number of taxa from 76 to 57. To examine strength of the associations of environmental gradients and species with ordination-axes, we performed correlation analyses using Spearman rank correlation. Spearman rank correlation is a nonparametric test that does not require data points to be linearly related with a normal distribution and or have constant variance about the regression line. The environmental matrix included data from physical-habitat surveys as well as information derived from topographic maps and communications with landowners (Table 2.1).

We used Indicator Species Analysis to determine if any particular species had high faithfulness and exclusivity to any season, harvest condition, or flow duration. The highest

possible indicator value, giving the percent perfect indication for a taxon, is 100. This occurs when a species is consistently and exclusively present in a particular group and does not appear in any other groups (Dufrene and Legendre 1997). The statistical significance of the indicator values was tested by the Monte Carlo method with 1000 randomized runs (McCune and Mefford 1999). Indicator values with a p -value <0.05 were considered a good indicator for a group.

To assess the classification strength of grouping sites by season, flow-duration, and harvest-condition we used mean-similarity analysis (Van Sickle and Hughes 2000). The overall classification strength of a grouping is measured by the difference between mean within-class and mean between-class similarities. This approach measured the degree to which the sites within the same group were more similar to each other, on average, than they were to sites in a different group (Van Sickle 1997a). Using the output from the multi-response permutation procedure (MRPP) from the PC-ORD program, we used MEANSIM Version 6.0 to calculate mean between-group similarities (Van Sickle 1997b). We remained consistent with NMS methodology by using Sorenson distance measure and rank-transformed MRPP, which analyzes the average within-group ranked-distances and is robust for heterogeneous data sets (McCune and Grace 2002).

The relationship of site elevation, harvest condition, flow duration, and riparian vegetation, with the mean nine-month water temperature and mean seasonal water temperature was investigated using multiple linear regressions. In one linear regression model with temperature as the response variable, elevation functioned as an independent continuous variable, while flow duration and harvest condition were “dummy variables” that turned on or off according to a site’s category. In another model, we used elevation, percent stream cover, percent riparian canopy cover of big and small trees, percent understory vegetation, and percent groundcover as independent, continuous variables and mean water temperature as the dependent, response variable. This methodology investigated whether harvest condition, flow duration, or riparian vegetation had detectable influences on water temperature while accounting for changes related to elevation.

RESULTS

Physical Habitat

Catchment area of the 20 streams sampled did not exceed 1 km² for any site and tended to be smaller for intermittent sites (Table 2.2). Channel dimensions, elevation, and reach slope were variable among sites and showed no consistent differences between categories of flow duration or harvest condition. Mean seasonal water temperature was coldest in spring and warmest in summer at all sites. During each season, mean water temperatures were not significantly different among treatments (Table 2.2). Intermittent and clearcut sites tended to have finer substrates than perennial or forested sites (Table 2.2). Intermittent streams, by definition, had no surface flow in summer, but flowed continuously in fall. At the start of spring sampling surface water was flowing at intermittent sites, but wetted width decreased during the collection period. Some reaches had discontinuous flow by the end of the spring sampling period.

Percent canopy, understory, and groundcover vegetation was lower at clearcut sites than at forested sites. Correspondingly, clearcut sites had less stream cover than forested sites in any season (Table 2.2). Logged streams had no buffer-strips and had been replanted with Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) seedlings in 2002 or 2003. Slash, large and small wood remaining after logging, was abundant at all clearcut sites and often covered portions of the stream channel. Sparse vegetation and topographic features, such as hillsides, provided stream shade at some sites. Forested sites were not logged within 34 years. At six of the ten forested sites, a mixture of deciduous and coniferous trees composed of Red alder (*Acer rubrus* Bong.), big-leaf maple (*Acer macrophyllum* Pursh.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and Douglas-fir made up the riparian canopy. Three of the forested sites, I-FOR40, P-FOR35, and P-FOR41, had canopies dominated by conifers. Only one site, I-FOR28, had a canopy dominated by deciduous trees. Understory vegetation was composed of tree saplings and shrubs of salmonberry (*Rubus spectabilis* Pursh) and thimbleberry (*Rubus parviflorus* Nutt.). Groundcover included salal (*Gaultheria shallon* Pursh), sword fern (*Polystichum munitum*

Kaulfuss), and many different herbaceous streamside plants, such as Siberian miner's lettuce (*Claytonia sibirica* L.) and bleeding heart (*Dicentra Formosa* [Haw.] Walp.).

Table 2.2. Median (minimum, maximum) of physical habitat variables of the four harvest condition and flow duration categories of this study. I-CUT refers to intermittent-clearcut sites, P-CUT to perennial-clearcut, I-FOR to intermittent-forested, and P-FOR to perennial-forested.

	Unit	I-CUT	P-CUT	I-FOR	P-FOR
Number of Sites	-	3	7	4	6
<u>Stream Variables</u>					
Active Channel Width	m	1.2 (0.3,2)	1.2 (0.7,3)	1.2 (1,2.3)	2.3 (1.4,3.3)
Bankfull Width	m	1.5 (1,2)	2.5 (1,3.5)	1.6 (1.5,4)	2.8 (1.5,4)
Sand & Fines ^{F1*}	%	86 (64,90)	52 (20,90)	80 (65,92)	33 (14,56)
Small Gravel, Sand, & Fines ^{F1*}	%	90 (64,92)	69 (33,90)	86 (81,92)	55 (33,64)
Coarse Substrate ^{F2**; H1*}	%	4 (0,4)	13 (0,34)	8.5 (0,15)	40 (29,65)
Organics	%	6 (4,36)	13 (2,47)	6 (3,8)	4 (2,7)
Summer Stream Cover ^{H1**}	%	48 (2,48)	17 (0,52)	97 (95,99)	93 (89,96)
Fall Stream Cover ^{H1**}	%	24 (11,42)	21 (3,57)	97 (90,100)	95 (92,99)
Spring Stream Cover ^{H1**}	%	17 (0,26)	11 (0,52)	94 (91,99)	94 (83,99)
Fast-Water Habitat Type	%	56 (33,100)	80 (11,100)	40 (0,100)	77 (55,100)
Slow-Water Habitat Type	%	11 (0,11)	18 (0,89)	20 (0,50)	23 (0,36)
Summer Water Temperature	°C	11.9 (11,12.6)	12.3 (11.2,13)	12.8 (10.9,13)	12.5 (11.4,13)
Fall Water Temperature	°C	10.3 (8.7,10.4)	10.0 (8.5,10)	9.6 (9.2,10.9)	9.2 (7.6,9.7)
Spring Water Temperature	°C	9.9 (8.7,10.1)	9.6 (7.8,10.3)	9.2 (7.5,9.5)	8.9 (7.8,9.4)
Reach Slope	%	15 (14,33)	21 (4,34)	10 (4,42)	19 (6,40)
Elevation	m	173 (146,294)	332 (132,571)	328 (181,564)	285 (145,615)
Catchment Area ^{F2*}	ha	3.0 (2.3,6)	4.6 (3.7,33)	3.4 (1.9,6)	16 (4.1,55)
<u>Riparian Variables</u>					
Big Trees Canopy ^{H1**}	%	0 (0,5)	0 (0,2.5)	15 (5,25)	25 (5,25)
Small Trees Canopy ^{H1**}	%	2.5 (0,2.5)	0 (0,15)	25 (25,58)	25 (25,88)
Non-Woody Understory ^{H1*}	%	25 (25,25)	25 (5,58)	73 (25,88)	88 (0,88)
Woody Understory	%	5 (2.5,5)	5 (5,15)	15 (5,25)	15 (0,25)
Non-Woody Ground Cover	%	58 (25,88)	25 (15,58)	88 (73,88)	88 (5,88)
Woody Ground Cover	%	5 (5,15)	5 (5,25)	5 (5,25)	5 (0,25)
Slash ^{H2**}	%	73 (58,88)	58 (25,88)	0 (0,0)	0 (0,15)
Stand Age ^{H1**}	yrs	1 (0,1)	0 (0,1)	62 (52,62)	36 (34,62)

F1: Intermittent > Perennial; F2: Perennial > Intermittent

H1: Forested > Clearcut; H2: Clearcut > Forested

* = $p < 0.01$; ** = $p < 0.002$

Table 2.3. Emergence rate, taxa richness, evenness, and Shannon-Weiner diversity for each season classified by harvest condition and flow duration (mean \pm s.d.). I-CUT refers to intermittent-clearcut sites, P-CUT to perennial-clearcut, I-FOR to intermittent-forested, and P-FOR to perennial-forested.

	Summer	Fall	Spring
<u>Total individuals emerged/m²/day</u>			
I-CUT	22.8 \pm 5.4	24.3 \pm 11.8	18.6 \pm 6.1
P-CUT	27.5 \pm 7.4	25.3 \pm 14.2	14.0 \pm 5.4
I-FOR	15.1 \pm 2.2	5.8 \pm 2.1	16.5 \pm 8.0
P-FOR	8.7 \pm 1.8	6.8 \pm 2.2	5.6 \pm 3.5
<u>Taxa Richness</u>			
I-CUT	18 \pm 3	12 \pm 4	17 \pm 4
P-CUT	18 \pm 1	15 \pm 5	20 \pm 3
I-FOR	16 \pm 3	9 \pm 3	15 \pm 4
P-FOR	13 \pm 2	9 \pm 1	12 \pm 4
<u>Evenness</u>			
I-CUT	0.54 \pm 0.19	0.31 \pm 0.07	0.57 \pm 0.15
P-CUT	0.42 \pm 0.14	0.33 \pm 0.10	0.59 \pm 0.10
I-FOR	0.60 \pm 0.08	0.42 \pm 0.11	0.68 \pm 0.09
P-FOR	0.57 \pm 0.13	0.31 \pm 0.06	0.65 \pm 0.15
<u>Shannon-Weiner (H')</u>			
I-CUT	1.57 \pm 0.63	0.78 \pm 0.26	1.59 \pm 0.36
P-CUT	1.22 \pm 0.40	0.89 \pm 0.33	1.77 \pm 0.29
I-FOR	1.64 \pm 0.26	0.92 \pm 0.39	1.83 \pm 0.30
P-FOR	1.42 \pm 0.24	0.66 \pm 0.14	1.57 \pm 0.38

Emergence Rates of Individual Orders and Functional Feeding Groups

Whether intermittent or perennial, more insects emerged at clearcut sites (Table 2.3). Harvest condition was a highly significant factor affecting total emergence rates through all seasons (Table 2.4). Though total emergence rates did not show a seasonal trend, season influenced the emergence rate of most individual orders (Table 2.4). Diptera, of which chironomids comprise 87%, showed high emergence at clearcut sites through all seasons with the highest emergence rates in summer and fall (Figure 2.2; Table 2.4). More Trichoptera emerged at clearcut sites, especially in summer, and harvest condition was significant factor through all seasons (Figure 2.2; Table 2.4). The emergence rates of Ephemeroptera and

Plecoptera were not significantly affected by harvest condition in any season. However, Plecoptera was affected by flow duration and had higher emergence from intermittent than perennial sites in the spring (Table 2.4; Figure 2.2).

Table 2.4. F-values with $p < 0.01$ from Repeated Measures Two-Way ANOVA analyses of taxa metrics and emergence rates (individuals emerged/m²/day) of all aquatic macroinvertebrates, individual orders, and functional feeding groups.

	Season (S)	Harvest (H)	Flow (F)	Interactions (F-value)
<u>Taxa Metrics</u>				
Taxa Richness	24.98*	17.13*	n.s.	n.s.
Evenness	25.43*	n.s.	n.s.	n.s.
Shannon-Wiener	34.84*	n.s.	n.s.	n.s.
<u>Emergence Rates (individuals emerged/m²/day)</u>				
Total Emergence	n.s.	37.48*	n.s.	n.s.
<u>Order</u>				
Ephemeroptera	21.15*	n.s.	n.s.	n.s.
Plecoptera	26.77*	n.s.	n.s.	SxF (9.26)
Trichoptera	20.73*	8.98	n.s.	n.s.
Diptera	6.09	40.79*	n.s.	n.s.
<u>Functional Feeding Group</u>				
Collector-Filterer	10.57	10.39	n.s.	SxF (6.05)
Collector-Gatherer	26.98*	n.s.	n.s.	n.s.
Shredder	8.26	n.s.	n.s.	n.s.
Scraper	n.s.	n.s.	n.s.	n.s.
Predator	12.29*	n.s.	n.s.	n.s.

* $p < 0.001$; n.s. = $p > 0.01$

The collector-filterer functional feeding group, dominated by the caddisfly *Wormaldia* in every season, had higher emergence from clearcut sites than forested sites (Figure 2.3; Table 2.4). Collector-filterers also had higher emergence from intermittent sites in the summer. Collector-gatherers, shredders, and predators were influenced by season. Shredders were primarily Plecoptera in the families of Leuctridae (*Moselia infuscata*) and of Nemouridae (*Zapada*, *Soyedina*, and *Malenka*) that emerged at higher rates from intermittent sites in the spring (Figure 2.3). More collector-gatherers, dominated by *Paraleptophlebia* and *Dipheter*, emerged in summer,

with fewer in spring and least in fall (Figure 2.3). Predators with the highest emergence rates were Ceratopogonidae (Diptera) in summer and *Sweltsa* (Plecoptera) in spring. Very few scrapers were collected in any season and neither harvest-condition nor flow-duration was influential (Figure 2.3; Table 2.4).

Taxa richness, evenness, and Shannon-Weiner diversity index were highly influenced by season with lower values in fall relative to summer and spring (Table 2.4). Taxa richness is affected by harvest condition with a higher number of taxa occurring at logged sites in every season (Table 2.3; Table 2.4). Very few taxa contributing to the higher richness at clearcut sites were collected from multiple streams. Of the 17 taxa that were unique to clearcut sites, only four appeared at five or more of the 10 logged streams (Diptera: Ephydriidae, Empididae *Neoplasta* and *Dolichocephala*; Trichoptera: Hydropsychidae *Homoplectra*). Of the eight taxa that were present only at forested sites, Perlodidae *Calliperla* (Plecoptera) appeared most frequently in spring samples at four of the 10 forested-sites. Forested sites, both intermittent and perennial, had slightly higher evenness than logged sites in all seasons and in both flow regimes (Table 2.3), but the difference was not significant ($p = 0.0178$; Table 2.4). The Shannon-Weiner index, which incorporates taxa richness and evenness, shows no influence by harvest condition or flow duration (Table 2.4). Taxa that could not be identified to the genus level for Ephemeroptera, Plecoptera, Trichoptera, or family level for Diptera were excluded from these taxa metrics and no differences in trends were observed when these ambiguous taxa were included.

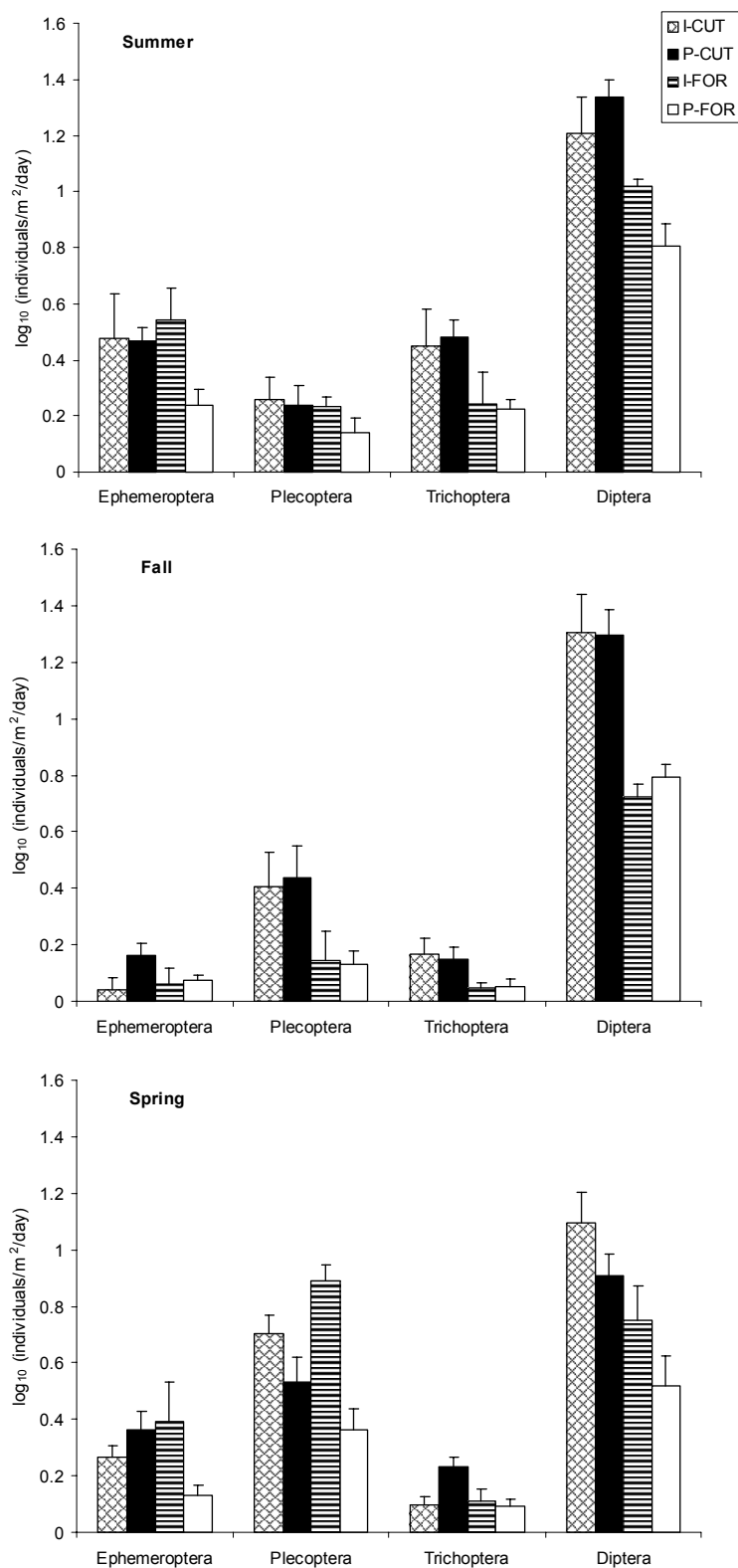


Figure 2.2. Emergence rates (mean + s.e.) of Ephemeroptera, Plecoptera, Trichoptera, and Diptera during summer, fall, and spring sampling. I-CUT is intermittent-clearcut, P-CUT is perennial-clearcut, I-FOR is intermittent-forested, and P-FOR is perennial-forested.

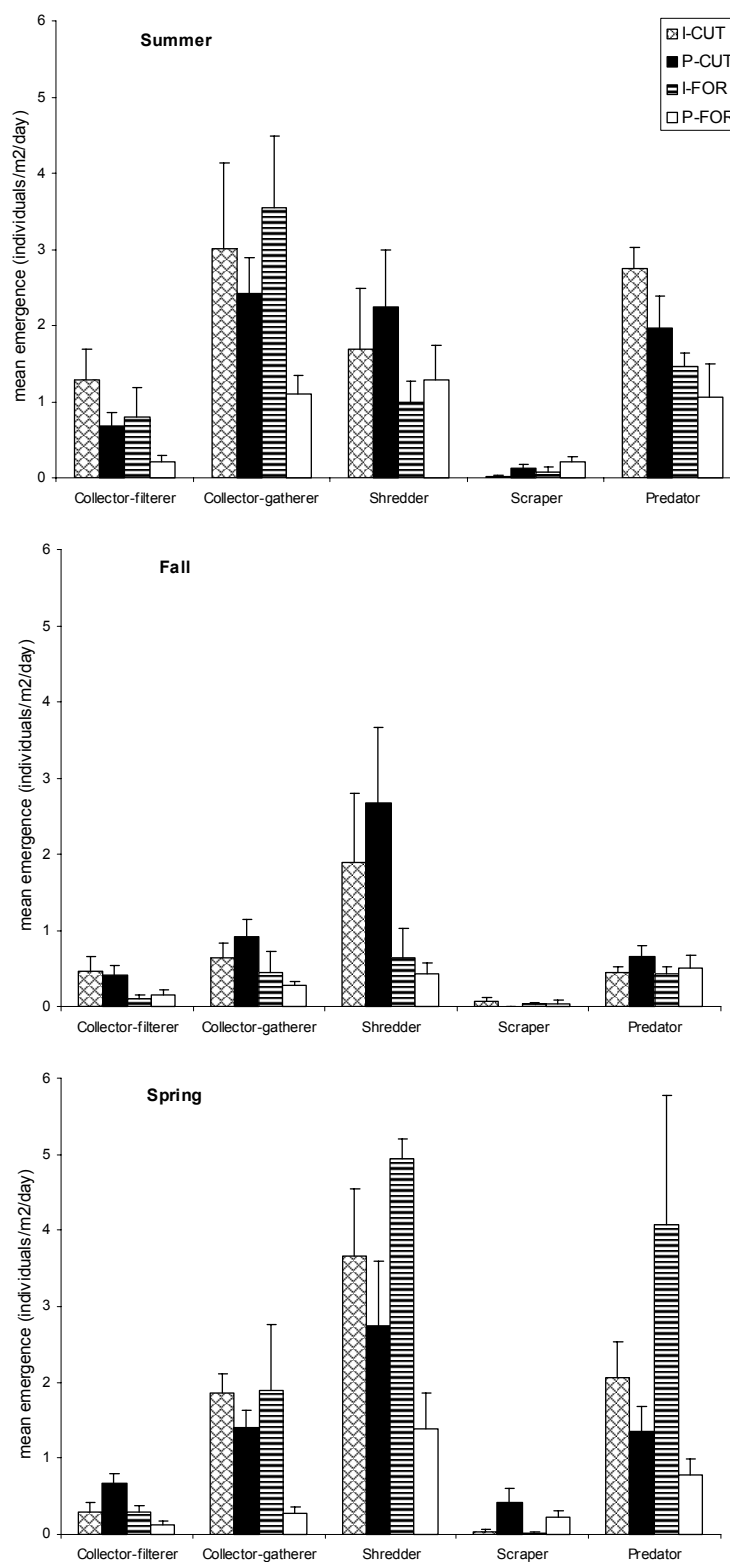


Figure 2.3. Emergence rates (mean + s.e.) of collector-filterer, collector-gatherer, shredder, scraper, and predator functional feeding groups during summer, fall, and spring sampling. I-CUT is intermittent-clearcut, P-CUT is perennial-clearcut, I-FOR is intermittent-forested, and P-FOR is perennial-forested.

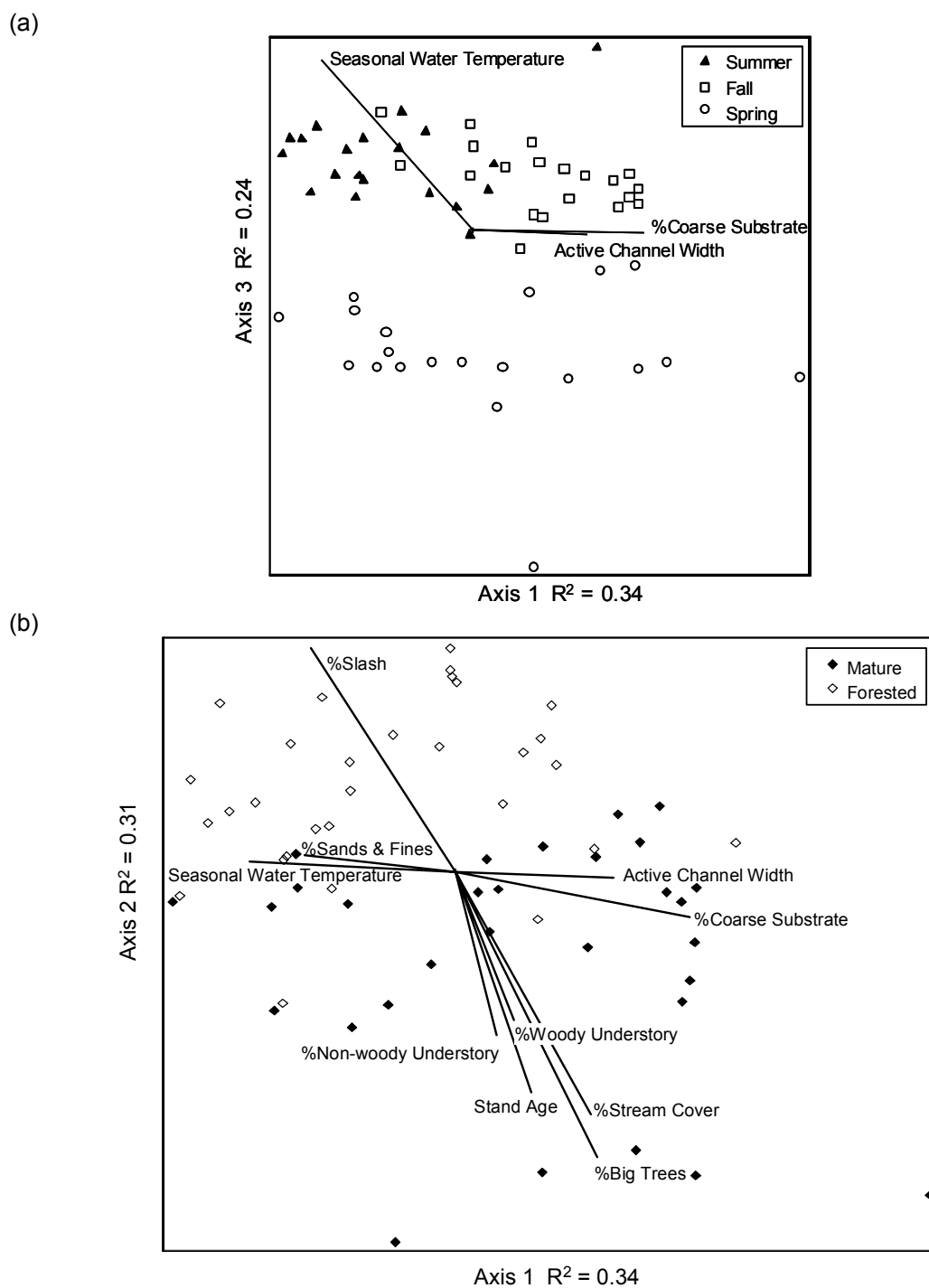


Figure 2.4. Nonmetric multidimensional scaling (NMS) ordination bi-plots of emergent macroinvertebrate assemblages sampled from 20 headwater study streams with vector overlay of environmental variables significantly correlated with the NMS axes. (a) Axis 1 and 3 with sites coded by season (summer, fall, and spring). (b) Axis 1 and 2 with sites coded by harvest condition (Forested vs. Clearcut).

Macroinvertebrate Assemblages and Gradients in Physical Habitat

NMS analyses of macroinvertebrate community assemblages for all seasons derived a three-dimensional solution (stress =11; $R^2=0.893$). In the Axis 1-3 plane, assemblages were separated according to season (Figure 2.4a). Spring assemblages separated from summer and fall assemblages along Axis 3. Summer and fall assemblages separated along Axis 1. Assemblages from clearcut sites separated from forested sites diagonally along Axis 1 and 2 (Figure 2.4b). In the Axis 1 by 2 plane, season is influential but less apparent; summer samples occur towards the right and fall samples are towards the left within each harvest-condition grouping. No distinct groupings were noted when sites were coded by flow duration.

Table 2.5. Spearman's r correlation coefficients >0.3 of measured physical habitat variables with ordination axes from the NMS-ordination of emergent macroinvertebrate data.

	Axis 1	Axis 2	Axis 3
<u>Stream Variables</u>			
Active Channel Width	+0.482**		
Bankfull Width	+0.389*		
Sand & Fines	-0.472**		
Small Gravel, Sand, & Fines	-0.416*		
Coarse Substrate	0.571**		
Organics	-0.478**		
Stream Cover	+0.383*	-0.551**	
Catchment Area	+0.459**		
Mean Seasonal Water Temperature	-0.549**		+0.618**
<u>Riparian Variables</u>			
Big Trees Canopy	+0.428**	-0.688**	
Small Trees Canopy	+0.456**	-0.590**	
Non-Woody Understory		-0.392*	
Woody Understory		-0.480**	
Non-Woody Ground Cover		-0.487**	
Slash	-0.412*	+0.623**	
Stand Age		-0.607**	

* $p<0.01$; ** $p<0.0001$

Many environmental gradients and particular taxa were strongly correlated with the NMS-ordination axes and clearly show seasonal and logging effects. Axis 1 correlated with both stream and riparian variables (Figure 2.4). Active channel width, bankfull width, and catchment area were detected as drivers in community assemblage relationships. Axis 1 was also positively correlated with percent riparian canopy that was higher at forested sites and negatively associated with higher slash density (Table 2.2; Table 2.5). On Axis 2, negative correlations with riparian variables that increased at forested sites were strong. These characteristics were the percentage of tree canopy, understory vegetation, herbaceous ground cover, stand age, and stream cover. Axis 2 was positively correlated with percent logging debris that increased at clearcut sites (Table 2.2; Table 2.5). Taxa that were indicator species for clearcut sites were usually negatively correlated with Axis 1 (Table 2.6; Table 2.7). Chironomidae were associated with all three axes, but were most highly correlated with Axis 2 ($r = 0.869$) and had a high percent perfect indication for clearcut sites (Figure 2.5a; Table 2.6; Table 2.7).

Axis 1 was negatively and Axis 3 was positively correlated with mean seasonal water temperature (Table 2.5). Temperature is a main driver in seasonal patterns of insect-emergence, affecting insect maturation rates and life histories. Species that had a strong negative association with Axis 3 emerged at a higher rate in spring. The stonefly, *Moselia infuscata*, was highly correlated with Axis 3 and was an indicator species for spring (Figure 2.5b; Table 2.6; Table 2.7). Another stonefly, Peltoperlidae *Yoraperla*, was only collected in spring and is also highly correlated with Axis 3 ($r = 0.626$). Species with a positive correlation with Axis 3 were more prolific in summer or fall. *Paraleptophlebia* (Ephemeroptera; $r = -0.835$), *Soyedina* (Plecoptera; $r = -0.740$), and Ceratopogonidae (Diptera; $r = -0.716$), were the most highly correlated with Axis 1 and were most abundant in summer (Figure 2.5c; Table 2.6; Table 2.7).

While flow duration was not a strong influence on overall emergence community patterns, there were several taxa that had high exclusivity and faithfulness to particular flow conditions (Table 2.7). *Wormaldia*, *Ostrocerca*, and Tipulidae were commonly found in intermittent sites. While *Ironodes*, *Parapsyche*, and *Dolophilodes*, were more commonly found at perennial sites. Of

these indicator taxa, only *Ironodes* and *Parapsyche* were unique to perennial flow duration. All other indicator species were found at both perennial and intermittent sites.

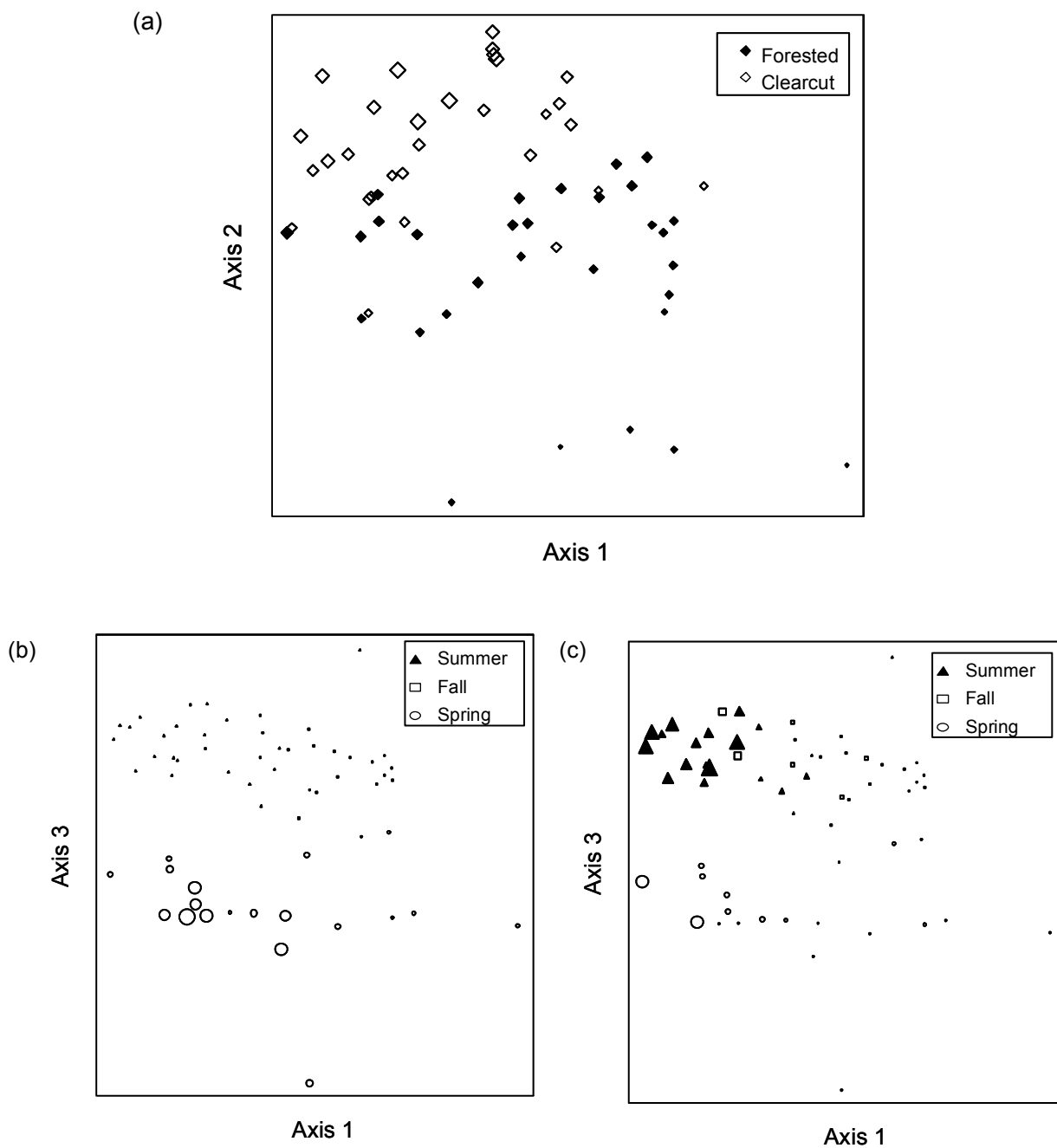


Figure 2.5. NMS-ordination plots with overlay of Chironomidae (a), *Moselia infuscata* (b), and *Paraleptophlebia* (c). The size of the symbols indicates the emergence rate of the taxa. The larger the symbol is, the higher the emergence rate.

Table 2.6. Individual macroinvertebrate taxa having Spearman's r correlation coefficients with NMS-ordination axes that are > 0.3 .

		Axis 1	Axis 2	Axis 3
<u>Ephemeroptera</u>				
Ameletidae	<i>Ameletus</i>	-0.358*		-0.480**
Baetidae	<i>Baetis</i>	+0.318		
Leptophlebiidae	<i>Paraleptophlebia</i>	-0.835**		
Heptegeneiidae	<i>Cinygma</i>			-0.309
	<i>Cinygmula</i>	+0.311		-0.319
<u>Plecoptera</u>				
Chloroperlidae	<i>Sweltsa</i>		-0.355*	-0.677**
Leuctridae	<i>Despaxia augusta</i>		+0.419**	+0.585**
	<i>Moselia infuscata</i>		-0.310	-0.794**
	<i>Paraleuctra</i>			-0.568**
Nemouridae	<i>Ostrocerca</i>		-0.348*	-0.356*
	<i>Soyedina</i>	-0.740**		
	<i>Zapada</i>	+0.403*	+0.470**	
Peltoperlidae	<i>Yoraperla</i>			-0.626**
Perlodidae	<i>Calliperla</i>			-0.335*
<u>Trichoptera</u>				
Hydropsychidae	<i>Homoplectra</i>			-0.317
Lepidostomatidae	<i>Lepidostoma</i>	-0.634**		+0.485**
Limnephilidae	<i>Chyranda centralis</i>			+0.301*
Philopotamidae	<i>Wormaldia</i>	-0.367*	+0.458**	
	<i>Dolophilodes</i>	-0.276		
Rhyacophilidae	<i>Rhyacophila</i>	-0.406*		
<u>Diptera</u>				
Ceratopogonidae		-0.716**		+0.583**
Chironomidae		-0.535*	+0.869**	+0.362*
Dixidae		-0.366*		+0.738**
Dolichopodidae		-0.390		+0.322
Empididae	<i>Clinocera</i>		+0.429**	
	<i>Dolichocephala</i>	-0.493**		
	<i>Neoplasta</i>		+0.303	
Ephydriidae		+0.344*		
Psychodidae		-0.735**		
Simuliidae				-0.395*
Tipulidae		-0.661**		+0.385*

* $p < 0.01$; ** $p < 0.0001$; all others correlation coefficients $p < 0.02$

Table 2.7. From the indicator species analyses, taxa with an indicator value (I.V.) with $p < 0.05$ showed high faithfulness and exclusivity for a season, harvest condition, and/or flow duration.

		Season	Harvest Condition	Flow Duration
<u>Ephemeroptera</u>				
Ameletidae	<i>Ameletus</i>	Spring (50)	Clearcut (41)	
Leptophlebiidae	<i>Paraleptophlebia</i>	Summer (63)		
Heptegeneiidae	<i>Ironodes*</i>			Perennial (23)
<u>Plecoptera</u>				
Chloroperlidae	<i>Sweltsa</i>	Spring (84)		
Leuctridae	<i>Despaxia augusta</i>	Fall (41)		
	<i>Moselia infuscata</i>	Spring (95)		
	<i>Paraleuctra</i>	Spring (50)		
Nemouridae	<i>Ostrocerca</i>	Spring (30)		Intermittent (22)
	<i>Soyedina</i>	Summer (53)		
	<i>Zapada</i>	Fall (76)		
Peltoperlidae	<i>Yoraperla</i>	Spring (65)		
Perlodidae	<i>Calliperla</i>	Spring (20)		
<u>Trichoptera</u>				
Hydropsychidae	<i>Homoplectra</i>	Spring (25)		
	<i>Parapsyche*</i>			Perennial (23)
Lepidostomatidae	<i>Lepidostoma</i>	Summer (80)		
Limnephilidae	<i>Chyranda centralis</i>	Summer (30)		
Philopotamidae	<i>Wormaldia</i>	Summer (47)	Clearcut (61)	Intermittent (58)
	<i>Dolophilodes</i>		Clearcut (43)	Perennial (43)
Rhyacophilidae	<i>Rhyacophila</i>	Summer (45)		
<u>Diptera</u>				
Ceratopogonidae			Clearcut (47)	
Chironomidae			Clearcut (62)	
Dixidae		Summer (57)		
Dolichopodidae		Summer (37)	Clearcut (32)	
Empididae	<i>Clinocera</i>		Clearcut (28)	
	<i>Dolichocephala</i>		Clearcut (53)	
	<i>Neoplasta</i>		Clearcut (27)	
Ephydriidae			Clearcut (23)	
Psychodidae			Clearcut (65)	
Simuliidae		Spring (30)		
Tipulidae			Clearcut (55)	Intermittent (56)

* Taxa had correlation coefficients with NMS-ordination axes with p -values > 0.05 .

Multiple linear regression identified elevation ($p < 0.0001$) as an important variable interacting with mean annual water temperature and seasonal mean water temperatures. All other parameters considered (harvest condition, flow duration, stream cover, and riparian vegetation of big and small trees, understory vegetation, and groundcover) were not as influential on mean water temperature ($p > 0.05$). A simple linear regression of mean water temperature and elevation showed that, in this study, water temperature decreased by 0.0043°C with every meter gained in elevation ($r^2 = 0.81$; Figure 2.6). This rate of cooling is consistent with the moist adiabatic lapse rate of 4°C per 1000-meter gain in elevation (Chapin et al. 2002). The mean water temperature during summer, fall, and spring had a similar rate of decreasing temperature with increasing elevation; however, the strength of the linear relationship between elevation and mean water temperature was weaker with r^2 's ranging from a low of 0.30 for summer and a high of 0.77 for spring. Though water temperature decreased with increasing elevation, elevation was not highly correlated with any NMS-axes; however, mean seasonal water temperatures were correlated with both NMS-axes 1 and 3.

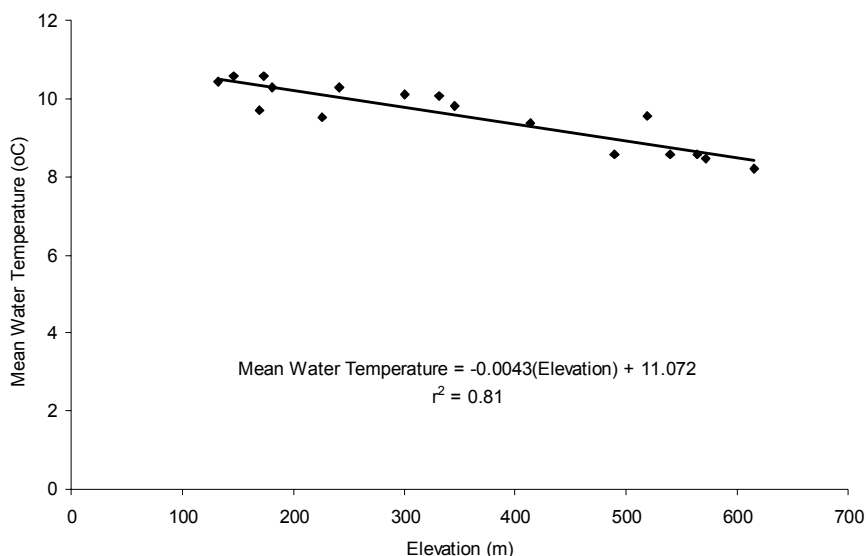


Figure 2.6. Linear relationship between sites' mean water temperature and elevation. Mean water temperatures are based on nine-months of observations, August 2003 through April 2004, for 17 of the 20 sites. The temperature recorders at the three excluded streams were either not retrieved or had significant gaps in data.

Table 2.8. Classification strengths from mean-similarity analyses of invertebrate assemblages grouped by season (summer, fall, spring), harvest condition (clearcut, forested), flow duration (intermittent, perennial), and combinations of harvest and flow classifications (I-CUT, P-CUT, I-FOR, P-FOR).

Grouping Variable (Groups)	Within-Group Similarity	Between-Group Similarity	Classification Strength
<u>Overall</u>			
Season	0.664	0.422	0.242
Harvest Condition	0.555	0.447	0.107
Flow Duration	0.509	0.494	0.016
Flow Duration and Harvest Condition	0.564	0.477	0.087
<u>Summer</u>			
Harvest Condition	0.579	0.427	0.152
Flow Duration	0.540	0.505	0.035
Flow Duration and Harvest Condition	0.616	0.525	0.141
<u>Fall</u>			
Harvest Condition	0.674	0.344	0.330
Flow Duration	0.512	0.494	0.018
Flow Duration and Harvest Condition	0.689	0.447	0.242
<u>Spring</u>			
Harvest Condition	0.529	0.474	0.054
Flow Duration	0.547	0.476	0.072
Flow Duration and Harvest Condition	0.596	0.477	0.119

Mean-similarity analyses confirmed the clear seasonal grouping seen in the NMS ordination with classification strength of 0.242. Grouping all sites by harvest condition, regardless of season, shows a weaker classification strength than seasonal groupings (Table 2.8) that is reflected in the slight overlap between groups in the NMS-ordination (Figure 2.4b). Analyses of each season individually reveal varying strengths of classification. Harvest condition shows the overall strongest classification strength in fall (0.330) and summer (0.152). In both summer and

fall, grouping by both harvest condition and flow duration shows a smaller gain in similarity than just classifying by harvest condition. Contrary to this trend, the comparatively lower classification strength in spring was best when sites were grouped by both harvest-condition and flow-duration, and not when these variables were used individually (Table 2.8).

DISCUSSION

Clearcut logging of headwater stream catchments increased the total emergence rates and altered the community assemblage of aquatic macroinvertebrates emerging from both perennial and intermittent headwaters we studied in the Central Oregon Coast Range. Logging activities that reduce canopy shading in streams with light-limited primary production has consistently resulted in increased algal biomass and ultimately leads to higher densities of benthic macroinvertebrates (Murphy et al. 1981; Hawkins et al. 1982; Noel et al. 1986; Brown et al. 1997; Duncan and Brusven 1995; Hetrick et al. 1998; Haggerty et al. 2004). Taxa that quickly exhibit increases in abundance after the food base is altered have short-generation times, allowing for rapid increases in populations when conditions are ideal (Newbold et al. 1980; Wallace and Gurtz 1986). A two to six fold increase in benthic invertebrate density has been observed when autochthonous production increases (Murphy et al. 1981; Noel et al. 1986). Whether caused by increased autochthonous production or other mechanisms, the higher numbers of adult aquatic insects emerging at our clearcut sites were consistent with patterns observed in benthic collections from other low-order streams.

Multivoltine insects, like Chironomidae and *Baetis*, commonly respond quickly to canopy reduction with increased density (Wallace and Gurtz 1986; Brown et al. 1997). In this study we saw higher emergence of both multivoltine and univoltine insects in clearcut catchments, indicating favorable conditions for these life histories. Chironomidae emergence was higher in clearcut streams; however *Baetis* was not frequently encountered and higher densities were not observed. The univoltine *Paraleptophlebia* was the most commonly collected Ephemeroptera, but it did not show a strong association with logged sites. The univoltine *Zapada* and *Moselia*

infuscata, which are common to headwaters, had higher emergence at logged sites in fall and spring, respectively. The Trichoptera *Wormaldia* is also univoltine, and consistently emerged at higher rates from logged than unlogged sites through the seasons. By definition, multivoltine taxa have multiple generations per year and generally have short generation times; these characteristics make them efficient colonizers and they can quickly increase in abundance when conditions are favorable. Univoltine insects develop within one year, but they can show high flexibility in their life cycles. Univoltine stoneflies and mayflies can have slower or faster life cycles, responding to factors such as photoperiod, food quantity, food quality, water temperature, oxygen concentration, and stream drying (Williams 1996; Dieterich 1992; Dieterich and Anderson 1995). A lack of indicator species for forested sites suggested no taxa or life histories were more successful under closed-canopy conditions.

Assemblages at clearcut sites not only had higher emergence, but differing taxa. Species richness is rarely affected by reduction in canopy (Carlson et al. 1990; Duncan and Brusven 1995). Changes in diversity in previous studies were primarily driven by increases in populations present in the creek prior to logging; usually species were not lost from the system if channel morphology and sediment loads did not change substantially (Carlson et al. 1990; Brown et al. 1997). In contrast to the other studies, we found differences in taxa richness between logged and unlogged sites, with clearcut sites generally having more taxa emerging than forested sites. The majority of taxa contributing to the difference in richness were somewhat unique to particular sites; i.e. they were found at one or two of the clearcut sites. The higher taxa richness detected at clearcut sites might have been a function of higher abundances collected at those sites; as more individuals are collected the likelihood of encountering rare species increases (Magurran 1988; McCune and Grace 2002). Of the four taxa found in at least half the clearcut sites, only *Homoplectra*, a filter-feeding caddisfly was definitively aquatic. The empidids (*Dolichocephala* and *Clinocera*) and ephyridae flies we collected were either aquatic or semiaquatic, and ephyrid can be highly flexible in both habitat and habit (McAlpine et al. 1981). *Homoplectra* is often associated with intermittent headwater seeps and springs in montane areas. While most of our

study streams had seeps and springs, *Homoplectra* was only collected from perennial and intermittent streams with clearcut catchments. Although *Homoplectra* was not an indicator species for clearcut sites, this is suggestive that seeps and springs are important under clearcut harvest-conditions.

Based on the River Continuum Concept (Vannote et al. 1980) and studies of logging impacts (e.g. Stone and Wallace 1998), we expected a shift in the predominant functional feeding group from shredders to scrapers when tree harvest reduced stream shading. We found very few emergent scrapers and no evidence of the predicted shift in functional composition based on harvest condition. Sampling immature macroinvertebrates in other headwaters of the Pacific Northwest, Haggerty et al. (2004) and Cole et al. (2003) noted a high density of collectors rather than scrapers in logged streams. In the Washington state study, high concentrations of in-stream slash shaded the streams and prevented an increase in algal growth commonly observed when riparian trees are removed (Haggerty et al. 2002). The authors considered the lack of increased autochthonous production the explanation for the lack of enhanced scraper abundance (Haggerty et al. 2004). Stacks of woody debris may also retain higher quantities of particles that collectors can thrive on, a net increase in food quantity rather than quality as expected when algal growth increases (Haggerty et al. 2002; Cole et al. 2003; Haggerty et al. 2004). Unlike the streams in Haggerty et al. (2002), streams in our study were not completely covered with logging debris, but slash was within the stream channel, covering the stream channel, or on the banks throughout every reach of our clearcut sites. More collector-filterers, particularly *Wormaldia*, emerged from our clearcut sites. Both *Wormaldia* and *Dolophilodes* were indicator species for clearcut conditions and these philopotamids feed upon very fine particles retained between the substrate. This is suggestive that differences in the functional composition in our streams may also be caused by increased food quantity through particle retention rather than higher food quality from increased primary production.

Our study was not an attempt to study annual emergence, but took snapshots in different seasons to characterize macroinvertebrate assemblages under different land management

histories and annual hydrologic variation. However, evidence from other studies in this region provides a temporal context for our work. Dieterich et al. (1997) found a distinct sequence of emergence in both laboratory rearing and in field collections from Oregon Coast Range headwaters, with a peak in shredder emergence in April, a subsequent peak in collector emergence in June, and scraper emergence peaking in between. Progar and Moldenke (2002) found similar temporal sequences in functional feeding group predominance in macroinvertebrates emerging from headwater streams in both the Cascade and Coast ranges of western Oregon. Based on patterns in these studies, it is unlikely the lack of scrapers could be an artifact of our study's temporal restrictions because we made collections during April and early May, encompassing the time period that both Dieterich et al. (1997) and Progar and Moldenke (2002) documented highest peaks in scraper emergence. As with Cole et al. (2003) and Haggerty et al. (2002; 2004), we had higher densities of collectors. Emergence of collector-filterers was higher from clearcut sites particularly in the summer.

According to Progar and Moldenke (2002) more insects emerge from flowing intermittent streams than from perennial streams. In contrast to his results, we found no differences in total insect densities between intermittent and perennial streams during periods when intermittent channels retained surface flow, e.g. fall sampling. Community assemblages of I-CUT sites responded similarly to timber harvest as assemblages of P-CUT sites and flow-duration had the weakest classification strength of the overall community. Our collection of aquatic insects even when intermittent channels were surface-dry in summer months indicated that the study streams most likely retained substantial subsurface flow that kept substrates moist. Muchow and Richardson (1999) also collected true aquatic insects emerging from small streams during periods with no perceptible flow on the coast of British Columbia. In addition, our study streams were only dry for a maximum of four months, retaining continuous surface flow for a minimum of eight months. Collecting year-round samples from Oregon Coast Range headwater streams, Dieterich (1992) concluded that when duration of continuous flow exceeds four to five months a

year the fauna of intermittent streams increasingly resembles that of perennial headwaters. Our results corroborate his work.

Although community assemblages did not differ based on flow duration, emergence rates of Plecoptera were higher at intermittent than perennial sites in the spring. Similarly Muchow and Richardson (1999) had higher emergence of Plecoptera from summer-dry streams, as much as twice the number from perennial streams. During our study, Plecoptera consistently emerged from I-FOR sites at higher rates than P-FOR sites, especially in spring when six times the number of stoneflies emerged per day from I-FOR sites compared to P-FOR sites. Only in spring did I-CUT sites have more Plecoptera emerging than P-CUT sites, but less dramatically than forested sites with only approximately 1.5 times emerging from I-CUT than P-CUT sites. Also similar to Muchow and Richardson (1999), *Despaxia augusta*, a stonefly with a two-year life cycle was collected at higher densities in our intermittent streams. *D. augusta* was also collected from intermittent sites in summer, when channels were surface-dry. The occurrence and life history pattern of *D. augusta* suggest that intermittent streams with predictable drying cycles provide sufficient refugia for taxa in wetted sediment even when there is no discernable surface flow.

Channel dimensions, substrate composition, and riparian vegetation were important controls on emergent macroinvertebrate assemblages in both intermittent and perennial headwater streams in each season. Hawkins et al. (1982) and Murphy et al. (1981) recognized the strong influence of sedimentation and reduction in shade from clearcut logging on abundances and feeding guild structure of benthic macroinvertebrates. They concluded that in the Cascade Range streams they studied, canopy reduction had a stronger effect on total abundance and guild structure than substrate character (Hawkins et al. 1982; Murphy et al. 1981). While our perennial sites shared similar lithology, clearcut sites tended to have finer substrates than forested sites suggesting sedimentation occurs through increased erosion and/or retention capacity from increased in-stream wood following timber harvest. We found high correlations of environmental gradients characterizing canopy cover and substrate composition, indicating that canopy reduction and substrate composition are both important influences on

emergent macroinvertebrate community in the headwaters of the Oregon Coast Range. The effects of substrate character and canopy structure could not be teased apart in our study. Measurements of canopy reduction (i.e. lower percent stream cover and riparian trees at clearcut sites) and of sedimentation (i.e. higher percent fines and sands at clearcut sites, higher percent coarse substrate at perennial-forested sites) were correlated in the NMS-ordination.

Community assemblages and abundances of emergent aquatic macroinvertebrates differed between clearcut and forested harvest conditions in these headwaters studied in the Central Oregon Coast Range. The functional composition was also altered, with more collector-filterers emerged from clearcut sites. Taxa richness was consistently higher at clearcut sites than forested sites with more types of taxa emerging during each sampling period. Although there was higher emergence of a few taxa, such as Chironomidae, at clearcut sites, evenness was not significantly higher at forested sites than clearcut sites. This is contrary to changes in diversity observed in other studies which detected no changes in species richness between logged and forested sites and observed higher evenness at forested sites driven primarily by increases in populations that were already present in the creek prior to logging (Brown et al. 1997; Carlson et al. 1990). Harvest-condition was more influential than flow-duration on emergent macroinvertebrate communities given that: emergent assemblages from intermittent streams did not differ from perennial streams, and summer-dry clearcut sites showed similar patterns to clearcut streams with continuous flow.

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Chapter 3

Influence of flow duration and clearcut logging on benthic macroinvertebrates in headwater streams of the Central Oregon Coast Range

Janel L. Banks

ABSTRACT

Our objective was to measure the effects of harvest class (logged and forested) and flow duration (perennial and intermittent) on the benthic aquatic macroinvertebrate assemblages of headwater streams. We compared the assemblages of benthic aquatic macroinvertebrates from 20 headwater streams in the central Oregon Coast Range that varied by harvest condition and flow-duration. Ten streams were located in catchments that were clearcut to the stream bank no more than a year prior to the start of sampling; three of these streams were intermittent and seven were perennial. Intermittent streams were summer-dry and retained surface-water for a minimum of eight months during the year, while perennial streams had surface flow year-round. The other ten streams (four intermittent and six perennial) were located in forested catchments that have not been logged for at least 34 years. Surber samples were taken from each stream in May 2004 and aquatic benthic macroinvertebrates were identified primarily to genus.

Two-Way ANOVA examined differences in total density and densities of individual orders and functional feeding groups. Regardless of harvest-condition, benthic invertebrates were more abundant in intermittent streams than in perennial streams. Trichoptera were also denser at intermittent sites. Densities of Diptera, Plecoptera, Ephemeroptera, and non-insects were not significantly different between categories of flow duration or harvest condition. Functional composition was also affected by flow-duration with collector-filterers, collector-gatherers, and predators occurring at higher densities at intermittent sites. Overall taxa richness was lower at intermittent sites. In a comparison of taxa lists, 40 taxa were unique to perennial streams and only 9 taxa were unique to intermittent streams. Evenness and Shannon-Weiner diversity did not differ between contrasting flow duration (intermittent vs. perennial) or harvest condition (clearcut vs. forested).

Non-metric multidimensional scaling (NMS) ordination analyses showed that community patterns of benthic aquatic macroinvertebrates differed by harvest condition within the perennial flow-duration class. Macroinvertebrate assemblages within intermittent streams did not differ between harvest conditions. Channel dimensions (active channel and bankfull width), mean

substrate diameter, percent stream-cover, mean water temperature, elevation, and percent small riparian trees influenced community assemblages. Substrate size, elevation-related differences in temperature, and catchment size were environmental gradients that appeared most influential on assemblages. The majority of perennial-clearcut sites had mean substrate diameter and macroinvertebrate community patterns more similar to intermittent-forested and intermittent-clearcut streams than to perennial-forested sites. The two perennial-clearcut sites that did not have assemblages similar to the other five perennial-clearcut sites had larger diameter substrate, higher elevation, larger catchment area, and cooler mean water temperatures than other perennial-clearcut sites.

In the Central Oregon Coast Range, intermittent headwater streams harbor many of the same taxa as perennial streams. Within flow-classes, assemblages of benthic aquatic macroinvertebrates in perennial streams were influenced more by clearcut logging than those in intermittent streams. Intermittent streams, which generally experience fewer flushing events and accumulate finer substrates than perennial streams, may be affected to a lesser degree by sedimentation caused by logging activity. Under both clearcut and forested harvest conditions, flow-duration is an important factor influencing densities and functional composition of aquatic benthic macroinvertebrates in the headwater streams we studied.

INTRODUCTION

Small streams in forested ecosystems are heavily shaded, and their fauna are dependent on a food base derived from allochthonous organic matter. In those streams, shredders and collectors, dependent on food sources derived from riparian inputs, tend to dominate functional feeding group composition (Cummins and Klug 1979; Vannote et al. 1980). After riparian tree removal, reduction in canopy increases total available solar radiation that reaches the stream bottom and decreases terrestrial canopy inputs (Stockner and Shortreed 1976). In streams that are not nutrient limited, algal communities respond to increased insolation with higher primary productivity (Murphy and Hall 1981; Shortreed and Stockner 1983; Noel et al. 1986). Thus, the energy base of harvested headwater streams potentially shifts from allochthonous inputs to autochthonous production of periphyton. Macroinvertebrates respond to the altered food base in a variety of ways, including higher densities and shifts in the predominant functional feeding group from shredders and collectors to scrapers (Hawkins et al. 1982; Murphy et al. 1981; Newbold et al. 1980; Noel et al. 1986). In many studies documenting changes in both sediment and temperature after logging, shift in the food base from allochthonous to autochthonous sources is the predominant factor affecting macroinvertebrate communities (Hawkins et al. 1982; Murphy et al. 1981; Newbold et al. 1980; Noel et al. 1986).

The impacts of clearcut logging activities on macroinvertebrate community are variable depending upon the width of the riparian buffer. Generally the light supply to the stream and autochthonous production increases as more riparian trees are removed, creating stronger effects on the macroinvertebrate assemblage with absent or narrow buffer strips (Newbold et al. 1980; Noel et al. 1986; Brown et al. 1997; Fuchs et al. 2003; Kiffney et al. 2003). Current Forest Practice Rules in Oregon do not require riparian buffers on fishless headwater streams, leaving these streams vulnerable to logging impacts (ODF 2004). Though these headwater streams harbor aquatic macroinvertebrates that serve as important resources to terrestrial biota and faunal communities downstream, few studies explore either the impact of logging on these small

streams or on their linkages to downstream reaches and terrestrial systems (Gomi et al. 2002; Piccolo and Wipfli 2002; Wipfli and Gregovich 2002; Moore and Richardson 2003).

Many headwater streams are subject to drying during low water years or seasons. Seasonally intermittent streams flow when the streambed is below the water table; they cease flowing during summer months when groundwater levels fall. Invertebrates dwelling in intermittent streams must be suited to survive yearly drying of the streambed. Behavioral and physical adaptations to survive annual drought include avoidance through diapause, emergence, or relocation to better habitat. In headwaters, invertebrates might burrow into the hyporheic zone, seek surface pools, or migrate downstream when channels start drying (Williams 1996). Intermittent streams often harbor species adept at colonizing recently disturbed or temporary habitat (Progar and Moldenke 2002). These taxa can be important colonizers of perennial systems disturbed by logging without buffers or with insufficiently wide buffers (Brown et al. 1997). However, evidence is growing that intermittent streams harbor both a subset of true aquatic fauna normally found in perennial streams and specialist temporary water taxa of whom little is known (e.g. Dieterich 1992; Muchow and Richardson 1999; Price et al. 2003).

Evaluations of logging impacts have traditionally investigated effects on fish-bearing perennial streams, but have not assessed effects on either fishless perennial streams or intermittent streams and their associated aquatic macroinvertebrate communities. To meet this need, this study examines impacts of logging on benthic macroinvertebrate assemblages in intermittent and perennial stream segments in the Central Oregon Coast Range. Our objective was to measure the effects of harvest class (logged and forested) and flow duration (perennial and intermittent) on the aquatic macroinvertebrate assemblages of headwater streams. Assemblages in perennial streams, whether logged or unlogged, were expected to be more similar to each other than to assemblages in intermittent streams because we anticipated flow persistence to show a stronger influence on composition than tree harvest. Within a flow-duration class, we expected that sites that had been clearcut would have higher densities of benthic

macroinvertebrates than sites with closed-canopies. We also expected functional composition to be dominated by grazers at clearcut sites and by collectors and shredders at unlogged sites.

METHODS

Study Design and Site Selection

This study had a fully crossed two-factor design with two levels of flow duration (perennial and intermittent) and of harvest condition (clearcut and unlogged). Ten of the twenty study sites were in basins clearcut within a year prior to the start of sampling. Typically, all trees were removed to the stream banks, and slash was burned within a year of harvest. The remaining ten sites, which we refer to as “forested”, had not been logged within 34 years prior to sampling and had a developed canopy layer (Table 2.2). Within each harvest-condition grouping, clearcut or forested, the streams were either perennial or dry during the summer months. We refer to the latter as “intermittent”. A site’s flow duration was predicted during site selection in spring 2003, prior to the start of fieldwork in summer 2003 and before stream channels were expected to lose surface flow. Final flow characterization was determined as streams either dried out or retained surface flow during summer months in 2003. Differences in the predicted and observed flow-duration resulted in an unbalanced study-design of three Intermittent-Clearcut (I-CUT), four Intermittent-Forested (I-FOR), seven Perennial-Clearcut (P-CUT), and six Perennial-Forested (P-FOR) sites.

All 20 study-streams were zero- to first-order headwater streams located in the Central Oregon Coast Range off of Highway 34 between the towns of Philomath and Alsea (Figure 2.1). The region has a temperate marine climate with cool, rainy winters and temperate, drier summers (Taylor & Hannan 1999). Through the cooperation of Weyerhaeuser Company and the Salem District of the Bureau of Land Management (BLM), access to both private and public lands in the Coast Range was possible. We studied topographic maps and aerial photographs to identify potential sites. Field reconnaissance was performed to select 20 sites that were safely accessible and had active channel widths less than 4 m with the desired harvest and flow conditions.

Field Sampling and Laboratory Methods

A 40-meter study reach was delineated at each stream. As explained in Methods of Chapter 2, we characterized the physical habitat of each reach during summer low-flows in August 2003. Based on information derived from the modified Wolman pebble-count, we calculated the \log_{10} of the geometric mean substrate diameter, which we refer to as the mean substrate diameter or substrate size in our analyses (Kaufmann et al. 1999; Table 3.1). Water temperature was recorded every 30-minutes from August 2003 to May 2004 using Onset StowAway TidbiT™ loggers. A site's mean water temperature during the study's nine-month duration was calculated by averaging the mean daily water temperatures for that site. In May 2004, we measured canopy cover with a spherical densiometer read at mid-stream in the four cardinal directions and converted to percent cover.

We collected benthic macroinvertebrates in May 2004 with a Surber sampler (mesh size of 500 μm) whose frame covered 0.09 m^2 of the streambed. All study streams retained surface water during our sampling; however, the wetted width at intermittent sites was narrowing as streams flow became restricted prior to becoming surface dry in the summer. At 18 of the 20 streams four samples were collected within the 40-meter reach: two from the upper 20 m and two from the lower 20 m of the reach. A total of 0.36 m^2 of streambed was sampled. Due to insufficient stream flow, only two samples were taken at the remaining sites, sampling 0.18 m^2 of streambed. Samples were stored in plastic Whirlbags®, preserved in 90% ethanol, and returned to the lab for processing.

At the lab, we pooled and physically mixed all samples collected at a site, then evenly distributed the material on a rectangular gridded sieve (Caton 1991). We randomly selected squares on the sieve and sorted the material under magnification until either at least 500 individuals/site were enumerated or the entire sample was sorted. If we counted 500 individuals before we finished processing a selected square, we continued searching until the material in that square was completely sorted. Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Megaloptera, and Odonata were primarily identified to genus using Merritt and Cummins (1996),

Wiggins (1996), or Stewart and Stark (2002). Chironomids were sorted to tribe and sent to EcoAnalysts Laboratory for identification to genus level. Non-insects were identified to various taxonomic levels: Nematoda to phylum; Oligochaeta, Copepoda, and Ostracoda to class; Acarina to suborder; Gastropoda to family; and Isopoda to genus. We assigned functional feeding groups from Merritt and Cummins (1996) and McAlpine et al. (1981). All insects assigned to either multiple or no functional feeding groups in the literature were not included in any further analyses of functional composition.

Table 3.1. Environmental variables derived from physical habitat surveys, topographic maps, and management history compiled for analyses of gradients in benthic community assemblages.

	Unit	Definition
<u>Stream Variables</u>		
Active Channel Width	m	Reach average of the active channel width
Bankfull Width	m	Reach average of the bankfull width
Mean Substrate Diameter	-	Log ₁₀ of geometric mean substrate diameter (mm)
Stream Cover	%	Cover from vegetation and topography
Fast-Water Habitat Type	%	Falls+Cascades+Rapids+Riffles
Slow-Water Habitat Type	%	Pools (All Types) + Glides
Mean Water Temperature	°C	Mean water temperature (August – April)
Slope	%	Slope of stream reach
Elevation*	m	Elevation of site
Catchment Area*	ha	Area draining into stream.
<u>Riparian Variables</u>		
Big Trees Canopy	%	Canopy (>5m high): cover by trees >0.3 DBH
Small Trees Canopy	%	Canopy (>5 m high): cover by trees ≤0.3 DBH
Non-Woody Understory	%	Mid-layer (0.5 to 5 high): herbaceous cover
Woody Understory	%	Mid-layer (0.5 to 5 high): woody cover
Non-Woody Ground Cover	%	Ground-layer (<0.5 m): woody cover
Woody Ground Cover	%	Ground-layer (<0.5 m): herbaceous cover
Slash	%	Ground-layer (<0.5 m): logging debris (slash)
Stand Age*	yrs	Years since last logged

* Information derived from topographic maps or landowner communications.

Data Analysis

Tallies were extrapolated to the total number collected and standardized to densities of individuals per square meter. Standardized data was used in all analyses of benthic macroinvertebrate assemblages and functional composition. We used Two-Way ANOVAs with Type III Sum of Squares to examine patterns in macroinvertebrate and functional feeding group densities associated with harvest condition and flow duration. A $p < 0.01$ indicated a difference between groups. Total density, the density of individual orders (Ephemeroptera, Plecoptera, Trichoptera, and Diptera and non-insects), and the densities of functional feeding groups (collector-gatherers, collector-filterers, shredders, scrapers, and predators) were analyzed under contrasting treatment conditions. We also calculated the relative abundance of each order and functional feeding group at a site and tested for differences between flow-duration and harvest-condition groupings with Two-Way ANOVAs.

To examine community patterns, we used Non-metric Multidimensional Scaling (NMS) in PC-ORD, version 4.20 (McCune and Mefford 1999). NMS is a non-parametric ordination method that performs well with community data that are heterogeneous (McCune and Grace 2002). We ran all NMS ordinations using a random starting configuration and the Sorensen distance measure to calculate dissimilarity between sites. To reduce the noise in the data so relationships in community assemblages could be discerned more readily, species that occurred at less than 2 sites were excluded and the data was $\log_{10}(x+1)$ transformed. Excluding rare taxa reduced the total number of taxa from 142 to 112. To examine associations of environmental gradients and individual taxa with ordination-axes, we used Spearman rank correlation. The environmental matrix included data from physical-habitat surveys as well as information derived from topographic maps and communications with landowners (Table 3.1).

We used Indicator Species Analysis to determine if particular species were strongly associated with any harvest condition or flow duration. The highest possible indicator value for a taxon is 100. This occurs when a species is consistently and exclusively present in a particular group and does not appear in other groups (Dufrene and Legendre 1997). The statistical

significance of the indicator values was tested by the Monte Carlo method with 1000 randomized runs (McCune and Mefford 1999). Indicator values with a p -value <0.05 were considered a good indicator for a group.

To assess species diversity on an equal basis, we adjusted raw counts to a common counting effort based on the lowest number, 445 individuals, enumerated from our sites (Ostermiller and Hawkins 2004). From a random subset of 445 individuals of the raw count at each site, we standardized densities (individuals/m²). Using the adjusted data, we compared total taxa richness, EPT richness, evenness, and the Shannon-Wiener diversity index using Two-Way ANOVAs and Type III Sum of Squares with a p -value <0.01 indicating a difference between groups. Shannon-Wiener diversity accounts for both evenness and taxa richness using the formula: $H' = -\sum p_i \ln p_i$ (Magurran 1988). The variable p_i is the proportion of individuals found in the i th taxa and is estimated by n_i / N (the number of individuals in the i th taxa/the total number of individuals). Evenness was calculated by dividing the Shannon-Weiner index by the natural log of taxa richness: $E = H' / \ln S$ (Magurran 1988).

RESULTS

Abundances and Richness of Benthic Taxa

In our headwater streams, flow persistence during the year was a much stronger influence on benthic macroinvertebrate densities than harvest history. Non-insects contributed an average of 33% of the benthic invertebrate density at intermittent sites and 21% at perennial sites, but non-insect densities were not significantly different between categories of flow duration (Table 3.2). Whether including or excluding non-insects, mean density of benthic macroinvertebrates was significantly higher at intermittent sites than perennial sites under both clearcut and forested harvest conditions (Figure 3.1; Table 3.2). While Ephemeroptera, Plecoptera, and Diptera showed no differences in densities between categories of flow duration or harvest condition, Trichoptera had higher densities under intermittent than perennial conditions (Figure 3.2; Table 3.2).

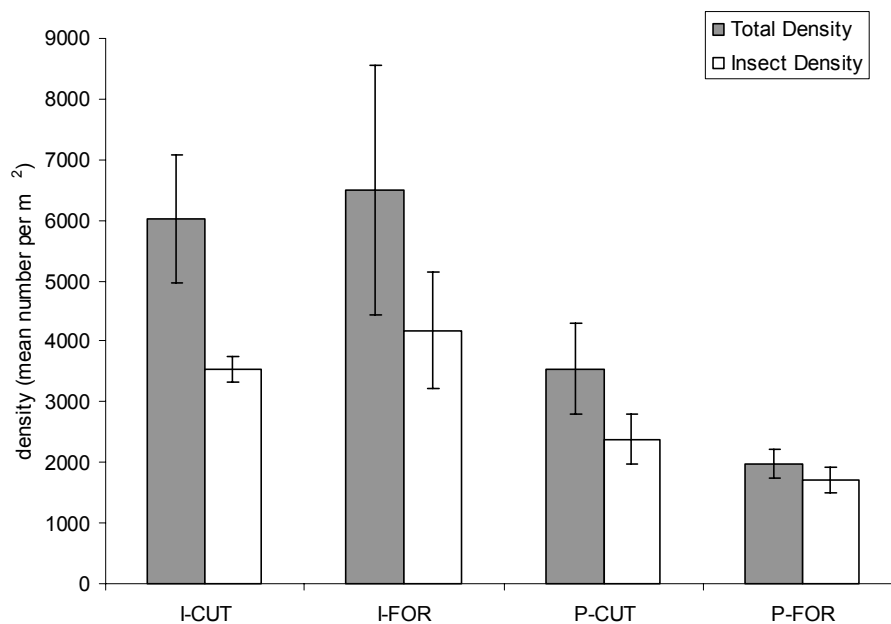


Figure 3.1. Mean macroinvertebrate density including non-insects (\pm se) and excluding non-insects (\pm se). I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

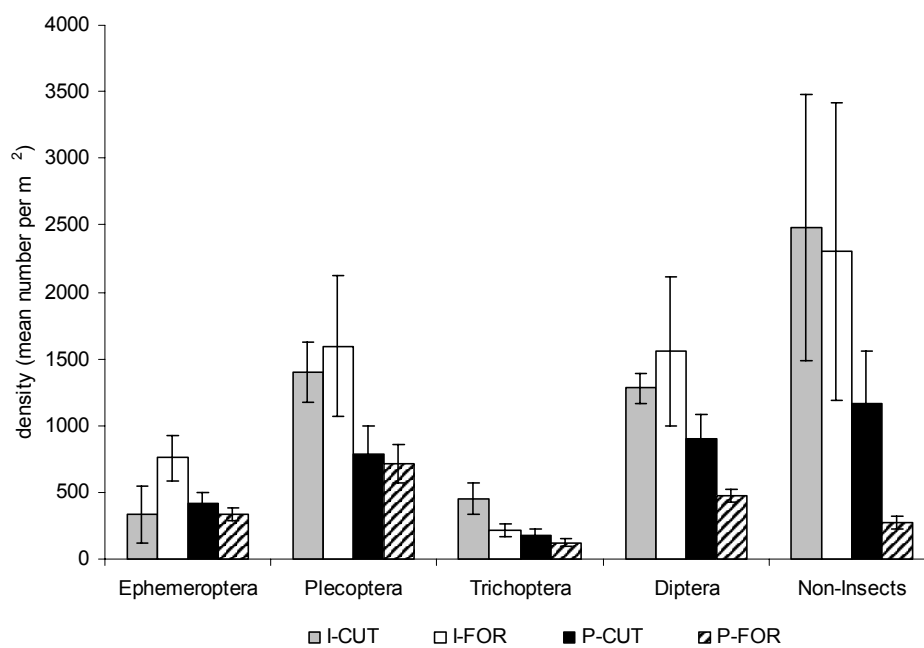


Figure 3.2. Mean macroinvertebrate densities of individual orders (\pm se). I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

Table 3.2. F-values from Two-Way ANOVA analyses of taxa metrics, densities, and relative abundances of individual orders and functional feeding groups. Taxa metrics are based on 445-count subset. All F-values reported have p -values <0.01 .

	Harvest (H)	Flow (F)	Interaction
<u>Taxa Metrics</u>			
Taxa Richness	n.s.	18.05*	n.s.
Evenness	n.s.	n.s.	n.s.
Shannon-Wiener Diversity	n.s.	n.s.	n.s.
Ephemeroptera Richness	n.s.	11.31	n.s.
Plecoptera Richness	n.s.	n.s.	n.s.
Trichoptera Richness	n.s.	n.s.	n.s.
EPT Richness	n.s.	8.71	n.s.
<u>Densities (individuals/m²)</u>			
Total Density	n.s.	10.50	n.s.
Insect Density	n.s.	11.89	n.s.
<i>Orders</i>			
Ephemeroptera	n.s.	n.s.	n.s.
Plecoptera	n.s.	n.s.	n.s.
Trichoptera	n.s.	10.58	n.s.
Diptera	n.s.	n.s.	n.s.
Non-Insects	n.s.	n.s.	n.s.
<i>Functional Feeding Group</i>			
Collector-Filterer	n.s.	15.10	n.s.
Collector-Gatherer	n.s.	17.70*	n.s.
Scraper	n.s.	n.s.	n.s.
Shredder	n.s.	n.s.	n.s.
Predator	n.s.	29.27*	n.s.
<u>Relative Abundances</u>			
<i>Orders</i>			
Ephemeroptera	n.s.	n.s.	n.s.
Plecoptera	n.s.	n.s.	n.s.
Trichoptera	n.s.	n.s.	n.s.
Diptera	n.s.	n.s.	n.s.
Non-Insects	n.s.	n.s.	n.s.
<i>Functional Feeding Group</i>			
Collector-Filterer	n.s.	n.s.	n.s.
Collector-Gatherer	n.s.	n.s.	n.s.
Scraper	n.s.	n.s.	n.s.
Shredder	n.s.	n.s.	n.s.

* $p < 0.001$; n.s. = $p > 0.01$

Benthic macroinvertebrate density ranged from 1,236 at a P-CUT site to 11,937 individuals per m² at an I-FOR site. Adjusting for individual site densities, benthic composition had no significant differences in the relative abundance of orders across sites (Table 3.2); however, there were some interesting trends in composition among different groups. The relative abundance of non-insects, Plecoptera, and Diptera comprised nearly a quarter or more of assemblage composition at I-CUT, I-FOR, and P-CUT sites (Figure 3.3). At P-FOR sites, Plecoptera and Diptera were the most abundant and non-insects were less dominant (Figure 3.3d). In a comparison of sites, Ephemeroptera were relatively more abundant at I-FOR sites than at I-CUT sites (Figure 3.3 a & b).

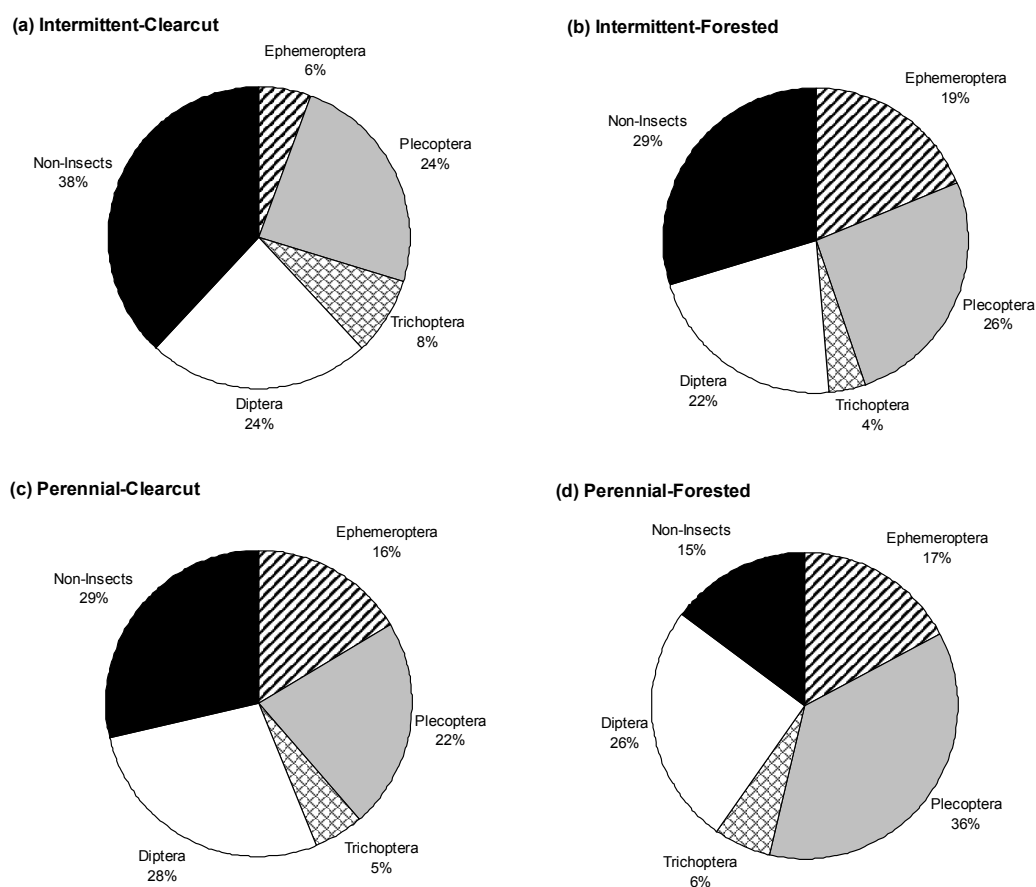


Figure 3.3. Mean relative abundance of taxonomic groups at intermittent-clearcut (a), intermittent-forested (b), perennial-clearcut (c), and perennial-forested (d) study sites.

Table 3.3. Taxa richness, evenness, and Shannon-Weiner diversity (mean \pm s.d.). I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

	I-CUT	I-FOR	P-CUT	P-FOR
Taxa Richness	47 \pm 2	42 \pm 5	52 \pm 5	54 \pm 4
Evenness	0.78 \pm 0.07	0.79 \pm 0.05	0.80 \pm 0.07	0.81 \pm 0.02
Shannon-Weiner (H')	3.00 \pm 0.25	3.00 \pm 0.21	3.20 \pm 0.29	3.20 \pm 0.14

Taxa richness was lower at intermittent sites than perennial sites (Table 3.2; Table 3.3). In particular, fewer Ephemeroptera and Diptera genera were represented at intermittent sites than perennial sites (Table 3.4). There were significantly fewer EPT taxa collected at intermittent sites, especially Ephemeroptera (Table 3.2). Despite differences in taxa richness, both evenness and the Shannon-Weiner diversity did not differ by flow duration or harvest class (Table 3.2; Table 3.3). The majority of taxa, 72%, were common to both intermittent and perennial sites. There were 40 taxa present at perennial sites, but not collected at intermittent sites (Table 3.5). Of these, only 7 occurred at more than half of the perennial sites: a water penny beetle *Acneus*; the mayflies *Baetis*, *Epeorus*, *Ironodes*, and *Cinygmula*; the caddisfly *Parapsyche*; and the Tanytarsini midge *Tanytarsus*. There were 9 taxa that were collected only at intermittent sites. Of these 9, 7 were collected only once and the remaining taxa, the caddisfly *Nerophilus californicus* and the Orthocladiinae chironomid *Smittia*, at only two sites. A total of 67 Diptera genera were collected during this study, 50 of them represented by Chironomidae; 24 of these midge genera were collected at no more than 3 of the 20 study sites.

Table 3.4. Number of benthic macroinvertebrate genera collected from each site class. Total: Number of different genera collected across all sites. I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

	Total	I-CUT	I-FOR	P-CUT	P-FOR
Ephemeroptera	10	3	5	10	10
Plecoptera	14	9	10	13	11
Trichoptera	16	10	10	11	13
Diptera	67	32	32	56	48
Non-insects	10	9	9	10	9

Table 3.5. The 40 taxa unique to perennial sites (n=13) and the 9 taxa unique to intermittent sites (n=7). The number in the parenthesis is the percentage of sites within a flow-duration class where the taxon was collected.

Unique to Perennial		Unique to Intermittent
<u>Coleoptera</u>	<u>Diptera - Chironomidae</u>	<u>Coleoptera</u>
<i>Acneus</i> (46%)	<i>Cladotanytarsus</i> (8%)	<i>Helichus</i> (14%)
<i>Heterolimnius</i> (8%)	<i>Cricotopus</i> (8%)	<u>Diptera</u>
<i>Zaitzevia</i> (23%)	<i>Heterotrissocladius</i> (8%)	Holorusia (14%)
<u>Ephemeroptera</u>	<i>Hydrobaenus</i> (8%)	<u>Diptera-Chironomidae</u>
<i>Baetis</i> (54%)	<i>Metriocnemus</i> (23%)	<i>Parachaetocladius</i> (14%)
<i>Cinygmula</i> (54%)	<i>Odontomesa</i> (8%)	<i>Smittia</i> (29%)
<i>Drunella</i> (31%)	<i>Pagastia</i> (23%)	<u>Plecoptera</u>
<i>Epeorus</i> (54%)	<i>Paracricotopus</i> (8%)	<i>Paraleuctra</i> (14%)
<i>Ironodes</i> (54%)	<i>Parakiefferiella</i> (23%)	<u>Megaloptera</u>
<u>Plecoptera</u>	<i>Paratendipes</i> (8%)	<i>Dysmicohermes</i> (14%)
<i>Doroneuria</i> (23%)	<i>Parorthocladius</i> (23%)	<u>Trichoptera</u>
<i>Kathroperla</i> (23%)	<i>Polypedilum</i> (15%)	<i>Cryptochia</i> (14%)
<u>Trichoptera</u>	<i>Prodiamesa</i> (8%)	<i>Nerophilus californicus</i> (29%)
<i>Anagapetus</i> (23%)	<i>Psectrotanypus</i> (8%)	<i>Philocasca</i> (14%)
<i>Chyranda centralis</i> (8%)	<i>Pseudorthocladius</i> (8%)	
<i>Neophylax</i> (23%)	<i>Rheotanytarsus</i> (23%)	
<i>Parapsyche</i> (46%)	<i>Synorthocladius</i> (15%)	
<u>Diptera</u>	<i>Tanytarsus</i> (46%)	
<i>Antocha</i> (8%)	<i>Thienemanniella</i> (31%)	
<i>Chelifera</i> (8%)		
<i>Dixella</i> (15%)		
<i>Glutops</i> (8%)		
<i>Oreothalia</i> (15%)		
<i>Tipula</i> (8%)		
<i>Thaumalea</i> * (8%)		

* Genus level identification based on adults collected through emergence trapping.

Functional Composition

The densities of collector-filterers, collector-gatherers, and predators were consistently higher at intermittent sites (Table 3.2; Figure 3.4). Functional feeding group densities were not apparently affected by harvest condition; however the dominant representative genera varied among sites. Fingernail clams were the dominant collector-filterers at most intermittent sites. The dominant collector-filterers at perennial sites varied between *Wormaldia*, *Dolophilodes*, *Homoplectra*, Simuliidae, as well as fingernail clams. *Paraleptophlebia*, oligochaete worms, *Brillia*, or *Rheocricotopus* were the dominant collector-gatherers at I-CUT, I-FOR, and P-CUT sites, while *Baetis*, *Dipheter*, or *Paraleptophlebia*, were dominant among P-FOR sites. Leuctridae and Nemouridae were the shredders most numerous at all sites with *Moselia infuscata*, *Malenka*, *Zapada*, and *Yoraperla* most commonly collected. Hydrobiidae snails were the most abundant scrapers at most sites. The stonefly *Sweltsa* were the dominant predator at many sites regardless of either harvest class or flow duration. At sites where *Sweltsa* was not dominant, either Ceratopogoninae or the Tanypodinae chironomid *Larsia* were more abundant.

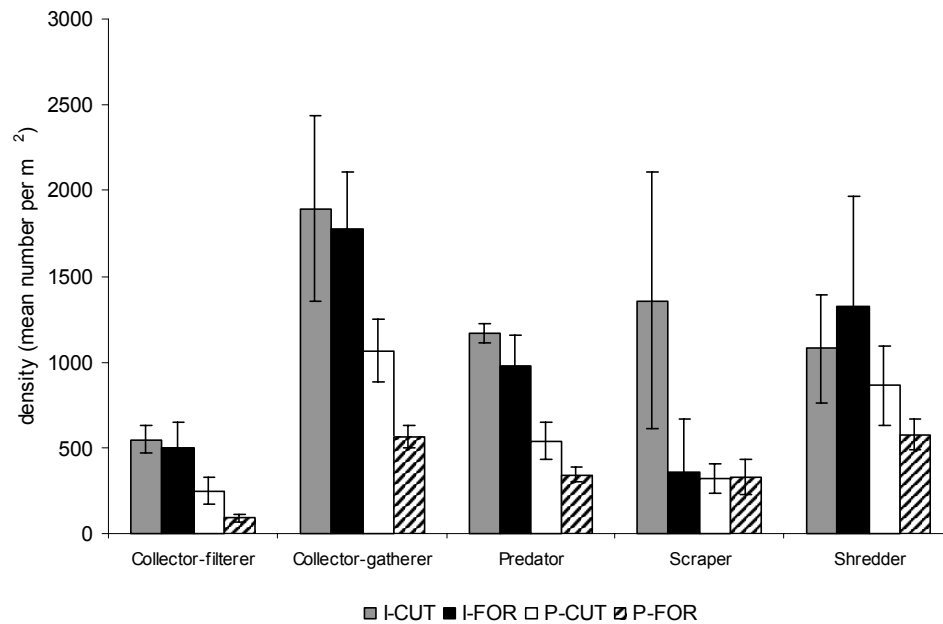


Figure 3.4. Mean density (\pm se) of individual functional feeding groups across all flow duration and harvest condition categories. I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

While the densities of many functional groups were higher at intermittent sites than perennial sites, the relative proportions at a site did not differ between categories of flow-duration or harvest-condition (Table 3.2). Collector-gatherers were the dominant functional group at I-CUT, I-FOR, and P-CUT sites, and averaged more than 30% mean relative abundance (Figure 3.5a-c). Collector-gatherers and shredders were co-dominant at P-FOR sites, with both having 30% mean relative abundance (Figure 3.5d). I-CUT sites had a slightly higher proportion of scrapers than I-FOR sites (Table 3.2); this resulted primarily from high abundances of Hydrobiidae snails.

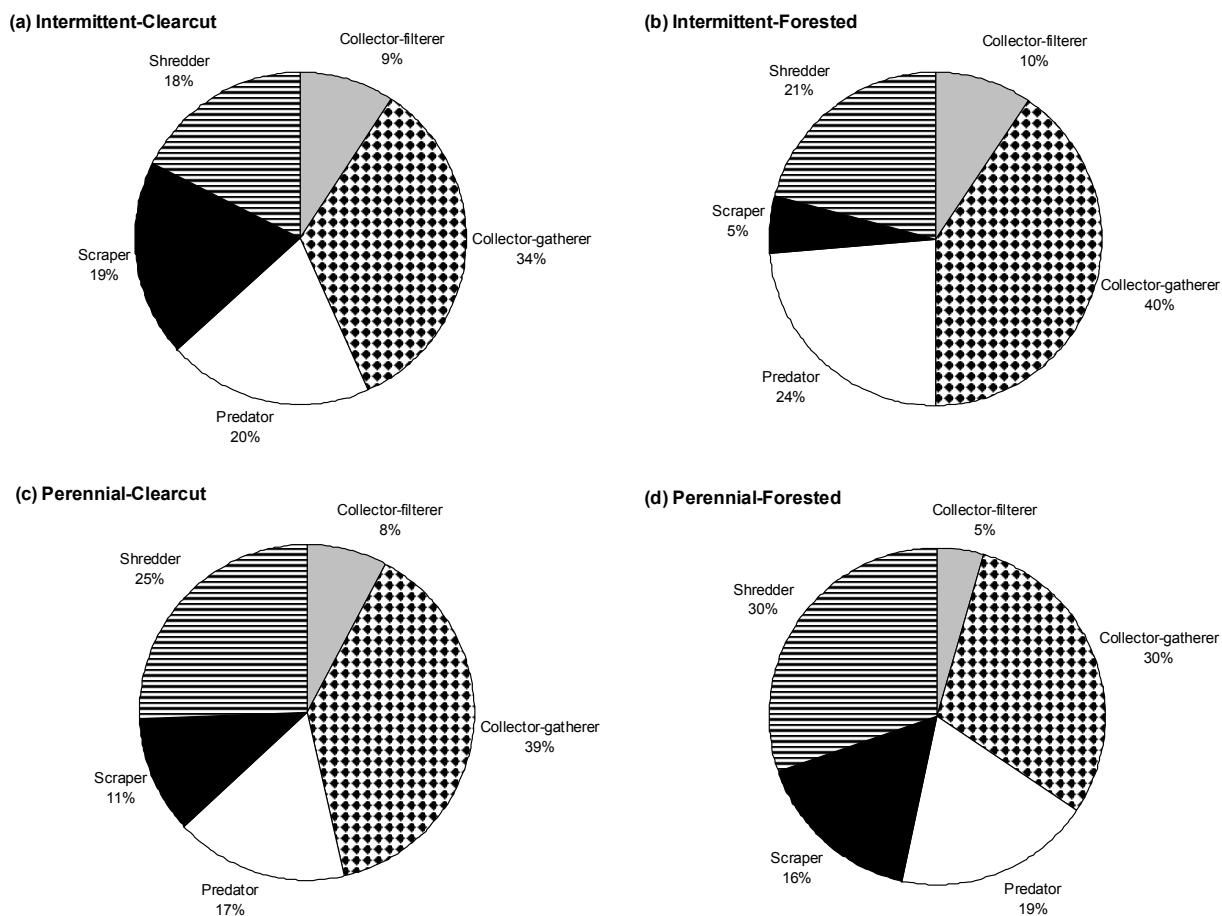


Figure 3.5. Mean relative abundance of functional feeding groups at intermittent-clearcut (a), intermittent-forested (b), perennial-clearcut (c), and perennial-forested (d) study sites.

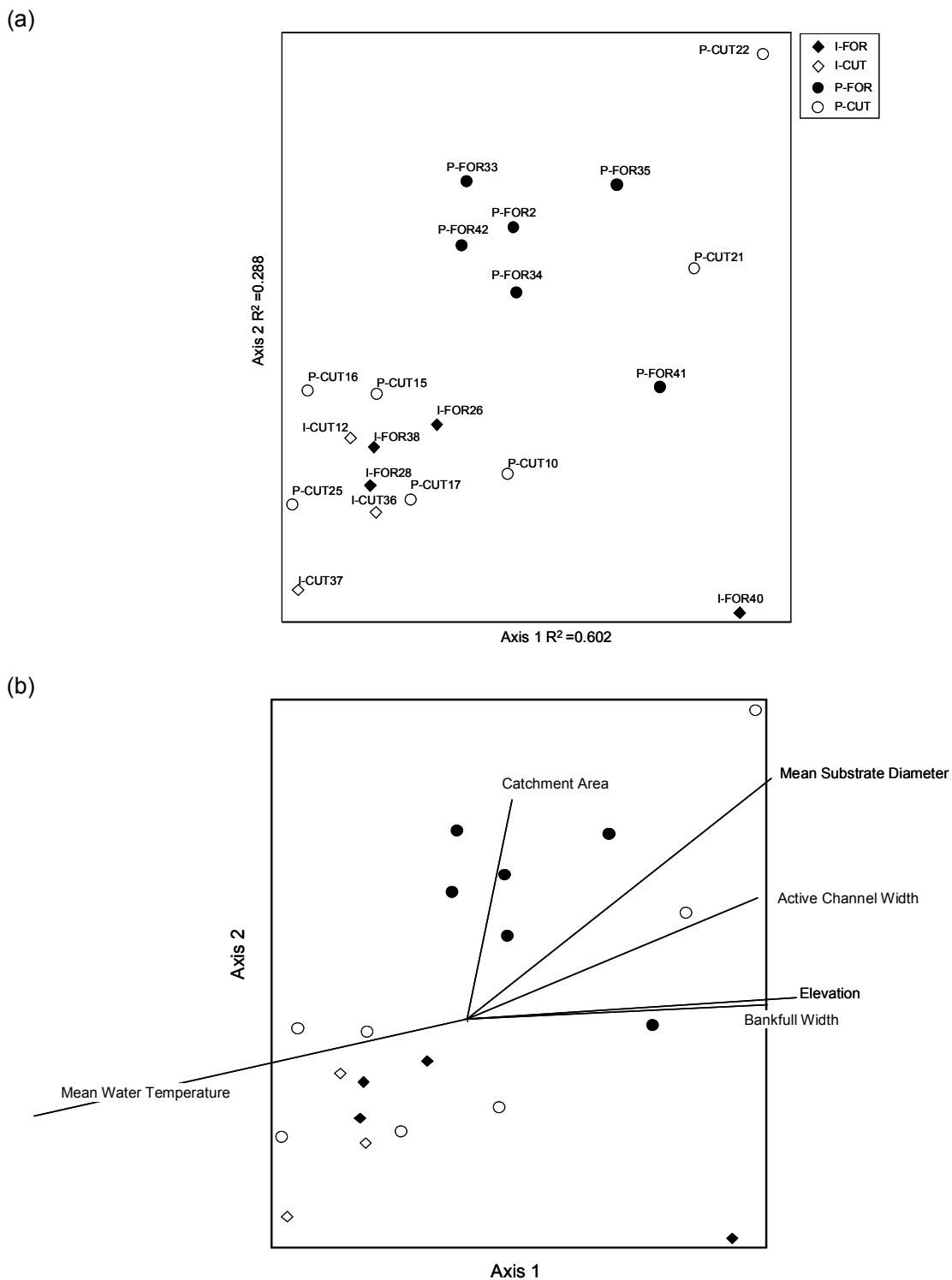


Figure 3.6. Nonmetric multidimensional scaling (NMS) ordination plots with the 20 study streams labeled (a) and with a vector overlay of environmental variables (b). I-CUT: intermittent-clearcut (n=3). I-FOR: intermittent-forested (n=4). P-CUT: perennial-clearcut (n=7). P-FOR: perennial-forested (n=6).

Community Patterns and Gradients in Physical Habitat

In the two-dimensional NMS-ordination solution, which accounted for 89% of the variability in the data with stress 12.5, P-CUT, I-CUT, and I-FOR sites were generally grouped together and P-FOR sites formed a separate grouping (Figure 3.6a). Axis 1, which explained 60% of the variability, was positively correlated with active channel width, bankfull width, elevation, stream cover and percent small riparian trees (Table 3.6; Figure 3.6b). Axis 2, to which catchment area was positively correlated, explained the remaining 29% of the variability. Both axes were positively correlated to mean substrate diameter and negatively correlated to mean water temperature.

Table 3.6. Spearman's r correlation coefficients >0.3 of measured physical habitat variables with NMS-ordination axes of benthic macroinvertebrate data. All reported coefficients have p -values <0.05 .

	Axis 1	Axis 2
<u>Stream Variables</u>		
Active Channel Width	+0.619*	n.s.
Bankfull Width	+0.645*	n.s.
Mean Substrate Diameter	+0.792**	+0.690**
Stream Cover	+0.464	n.s.
Fast-Water Habitat Type	n.s.	n.s.
Slow-Water Habitat Type	n.s.	n.s.
Mean Water Temperature	-0.764**	-0.528
Slope	n.s.	n.s.
Elevation	+0.623*	n.s.
Catchment Area	n.s.	+0.645*
<u>Riparian Variables</u>		
Big Trees Canopy	n.s.	n.s.
Small Trees Canopy	+0.455	n.s.
Non-Woody Understory	n.s.	n.s.
Woody Understory	n.s.	n.s.
Non-Woody Ground Cover	n.s.	n.s.
Woody Ground Cover	n.s.	n.s.
Slash	n.s.	n.s.
Stand Age	n.s.	n.s.

* $p < 0.01$; ** $p < 0.0001$; n.s. = $p > 0.05$

Table 3.7. Individual benthic taxa having Spearman's r correlation coefficients with NMS-ordination axes that are >0.3 and with $p < 0.05$.

		Axis 1	Axis 2
<u>Ephemeroptera</u>	<i>Baetis</i>	+0.521	+0.766**
	<i>Drunella</i>	+0.517	+0.578*
	<i>Cinygmula</i>	+0.538	+0.669*
	<i>Epeorus</i>	+0.674*	+0.768**
	<i>Ironodes</i>	-	+0.515
	<i>Paraleptophlebia</i>	-0.469	-0.473
<u>Plecoptera</u>	<i>Moselia infuscata</i>	-0.493	-
	<i>Zapada</i>	-0.528	-
<u>Trichoptera</u>	<i>Anagapetus</i>	+0.539	+0.527
	<i>Homoplectra</i>	-0.491	+0.605*
	<i>Psychoglypha</i>	-0.732**	-0.672*
	<i>Wormaldia</i>	-0.640*	-
<u>Diptera</u>	<i>Ceratopogoninae</i>	-0.854**	-0.636*
<u>Orthocladinae</u>	<i>Brillia</i>	-0.609*	-0.484
	<i>Chaetocladius</i>	-0.551	-0.474
	<i>Corynoneura</i>	-0.811**	-
	<i>Heleniella</i>	-	+0.463
	<i>Limnophyes</i>	-0.515	-
	<i>Parakiefferiella</i>	-	+0.430
	<i>Parametriocnemus</i>	-0.537	-
	<i>Parorthocladus</i>	+0.549	+0.513
	<i>Psilometriocnemus</i>	-0.684**	-
	<i>Rheocricotopus</i>	-0.718**	-0.690**
	<i>Smittia</i>	-	-0.518
	<i>Tvetenia bavarica gr.</i>	-0.677**	-
<u>Tanypodinae</u>	<i>Macropelopia</i>	-	-0.604*
	<i>Natarsia</i>	-	-0.543
	<i>Reomyia</i>	-0.460	-0.509
<u>Tanytarsini</u>	<i>Rheotanytarsus</i>	+0.515	+0.476
<u>Dixidae</u>	<i>Meringodixa</i>	-0.736**	-
<u>Psychodidae</u>		-0.598*	-
<u>Tipulidae</u>	<i>Dicranota</i>	-0.730**	-
<u>Non-Insects</u>	<i>Acarina</i>	-0.530	-0.551
	<i>Isopoda</i>	-0.480	-0.504
	<i>Copepoda</i>	-0.705**	-0.638*
	<i>Nematoda</i>	-0.788**	-0.716**
	<i>Oligochaeta</i>	-0.790**	-0.679**
	<i>Ostracoda</i>	-	-0.519
	<i>Pisidiidae</i>	-0.722**	-0.721**

* $p < 0.01$; ** $p < 0.0001$; n.s. = $p > 0.05$

Sites with finer substrate and warmer temperatures were to the left of the NMS-ordination graph (Figure 3.6b). P-FOR sites, grouped to the right, had coarser substrate and less sands and fines than P-CUT, I-CUT, or P-FOR sites (Two-Way ANOVA; Tukey-Kramer HSD; $p < 0.05$). P-CUT22, P-CUT21, P-FOR35, P-FOR41, and I-FOR40, on the right side of Axis 1 (Figure 3.6a), were at elevations near to or above 500 meters and had mean water temperatures ranging between 8.2° to 8.6° C. Other sites were a degree or more warmer in mean water temperature and were below 350 m elevation, with the exception of P-CUT10 at 519 m and I-FOR38 at 414 m. At P-CUT22 and P-CUT21, the only perennial-clearcut sites that had assemblages similar to perennial-forested sites, substrates were larger in mean diameter than at other clearcut sites (Figure 3.6b). P-CUT22 and P-CUT21 also had larger active channel widths, bankfull widths, and catchment areas than other clearcut sites. I-FOR40 had the widest active channel and largest catchment area of all the intermittent sites. Forested sites, whether perennial or intermittent, had higher percentages of stream cover and small riparian trees.

Generally taxa that were negatively correlated with either NMS-axis exhibited higher densities at clearcut and/or intermittent sites, and taxa that were positively correlated with either NMS-axis had higher densities at perennial and/or forested sites (Table 3.7). Non-insects, *Paraleptophlebia*, *Moselia infuscata*, *Zapada*, *Psychoglypha*, *Wormaldia*, and *Homoplectra* were all negatively correlated with at least one NMS-axis (Table 3.7). Most of the midge genera correlated with NMS-axes were more abundant at clearcut and/or intermittent sites. Four Chironomidae genera, three of which are unique to perennial sites, were positively correlated with NMS-axes and had the highest densities at P-FOR or P-CUT sites with larger substrate (Table 3.5; Table 3.7). *Baetis*, *Drunella*, *Cinygmula*, *Epeorus*, *Ironodes*, and *Anagapetus* were also positively correlated with NMS-axes, and were more common at perennial sites (Table 3.7).

Many of the indicator species for classes of flow-duration or harvest-condition were also correlated to NMS-axes. Among taxa with negative correlations to NMS-axes, *Paraleptophlebia*, *Rheocricotopus* and *Reomyia* were indicator species for intermittent flow-duration (Table 3.7; Table 3.8). Non-insects were usually good indicators of intermittency having high percent perfect

indication for Copepoda, Nematoda, and Oligochaeta. *Chaetocladius* and *Psychoglypha*, also negatively correlated, were indicators for clearcut harvest-condition. Among the negatively correlated Diptera, only Ceratopogoninae served as a reliable indicator of both clearcut and intermittent sites. *Baetis*, *Cinygmula*, *Epeorus*, and *Ironodes* were all positively correlated to NMS-axes, and were indicator species for perennial flow-duration (Table 3.7; Table 3.8).

Table 3.8. From the indicator species analyses, the indicator values of percent perfect indication with $p < 0.05$ are given for taxa showing high faithfulness and exclusivity for harvest condition or flow duration.

Harvest Condition		
	<u>Clearcut</u>	<u>Forested</u>
Ephemeroptera	-	<i>Cinygma</i> (62)
Plecoptera	-	<i>Malenka</i> (83)
Trichoptera	<i>Psychoglypha</i> (58)*	-
Diptera	Ceratopogoninae (60)*	<i>Stilocladius</i> (50)
	<i>Chaetocladius</i> (55)*	-
	<i>Eukiefferiella</i> (70)	-
	<i>Krenopelopia</i> (55)	-
Flow Duration		
	<u>Perennial</u>	<u>Intermittent</u>
Ephemeroptera	<i>Baetis</i> (54)*	<i>Paraleptophlebia</i> (55)*
	<i>Cinygmula</i> (54)*	-
	<i>Epeorus</i> (54)*	-
	<i>Ironodes</i> (54)*	-
Plecoptera	<i>Yoraperla</i> (64)	-
Trichoptera	-	-
Diptera	<i>Simuliidae</i> (77)	<i>Ceratopogoninae</i> (61)*
	-	<i>Rheocricotopus</i> (71)*
	-	<i>Reomyia</i> (64)*
Non-Insects	-	Copepoda (63)*
	-	Nematoda (64)*
	-	Oligochaeta (59)*

* Taxa had correlation coefficients with NMS-ordination axes with p -values < 0.05 .

Indicator species analyses also revealed taxa that were not correlated with either NMS-axes, but had significant percent perfect indication. *Malenka*, *Cinygma*, and *Stilocaldus* were not

correlated with either axis, but were strong indicators for forested harvest-condition (Table 3.7; Table 3.8). The chironomids, *Eukiefferiella*, *Krenopelopia*, and *Stilocaldius*, were indicators for clearcut harvest-condition (Table 3.8). Simuliidae and *Yoraperla* were the only strong indicators for perennial flow-duration that were not correlated with the NMS-axes. All indicator species for intermittent flow-duration were correlated to the NMS-axes.

DISCUSSION

Densities of aquatic macroinvertebrates were higher at the intermittent sites we studied than the perennial streams. Dieterich (1992) provides one of the few published studies of the macroinvertebrate fauna in headwater, summer-dry streams in the Coast Range of Oregon. While comparisons of our benthic densities with Dieterich's (1992) findings must be considered with some caution because of differences in sampling methods (multiple leaf packs from December through September vs. Surber samples in May) and density measurements (individuals per leaf pack vs. individuals per square meter), there were no other quantitative measurements of benthic fauna reported in the literature we reviewed for similar streams. Based on a comparison of flow duration and vegetative cover of the seven headwater-streams that Dieterich (1992) sampled with the 20 streams we sampled: two of Dieterich's study streams were analogous to our study's intermittent-forested sites; two flowed through meadows and were comparable to our intermittent-clearcut sites; one was similar to our perennial-forested sites; the remaining two streams only had surface flow following storm events, flowed for less than 3 months of the year, and were not comparable to our study's streams. Dieterich (1992) found higher density of benthic macroinvertebrates in the permanently flowing stream than in the four summer-dry streams in the forested and meadowland catchments. The pleurocerid snail *Juga silicula* and midges contributed primarily to the higher density found at the perennial site (Dieterich 1992). Contrary to his results, we found that benthos density was higher at intermittent sites than at perennial sites irrespective of harvest condition. In our study, *Juga sp.* was infrequently collected at perennial sites and was a minor contributor to benthic density. We also found higher midge density at our intermittent sites

than our perennial sites. While Dieterich (1992) found lower densities of Diptera, Plecoptera, and Trichoptera at his summer-dry sites, we found no differences in densities of Diptera and Plecoptera and higher densities of Trichoptera at our intermittent sites than our perennial sites. Ephemeroptera was the only order that Dieterich (1992) found higher densities in his forested summer-dry streams than his perennial site. Contrary to this, we found no significant differences in the densities of mayflies between categories of flow-duration.

Many studies have documented higher benthic density in streams with clearcut catchments than streams flowing through a forested reach (e.g. Murphy et al. 1981; Hawkins et al. 1982; Duncan and Brusven 1985; Haggerty et al. 2002; Cole et al. 2003; Fuchs et al. 2003; Price et al. 2003; Haggerty et al. 2004; Hernandez et al. 2005). While our perennial-cut sites tended to have slightly higher benthic densities than perennial-forested sites, we found no significant differences in densities based on harvest condition. The researchers in these previous studies employed a wide range of sampling techniques to sample mainly perennial streams, including sediment cores (Hernandez et al. 2005), substrate baskets (Haggerty et al. 2002; Haggerty et al. 2004), and Surber sampling (Hawkins et al. 1982; Cole et al. 2003; Fuchs et al. 2003). There is insufficient information to determine if our contrasting observations resulted from divergent sampling techniques, differences in flow duration, or the size of the streams we sampled.

We expected scrapers to have higher densities at clearcut sites than forested sites, but there were no abundance differences between harvest classes. Gatherers, filterers, and predators were more abundant at intermittent than perennial sites, regardless of harvest class. Functional composition of macroinvertebrates in temporary waters is often affected by a seasonal succession of species while streams go through three different stages: 1) a fall-winter running water stage; 2) a spring pool phase while flow stops; and 3) a summer terrestrial stage (Williams and Hynes 1976; Williams 1996). Although collector-gatherers are well represented in all stream stages, Williams (1996) noted that the functional community was dominated by collector-gatherers during fall and winter when temporary streams have continuous flow. In our study, this

dominance persisted into spring. While studying two intermittent streams in Australia, Boulton and Lake (1992) observed a peak in predator numbers when streams were drying in late spring. We sampled in May while intermittent streams were transitioning between the running-water and the spring-pool stage, which might account for high concentrations of predators and collectors at our intermittent sites.

Sweltsa, Ceratopogoninae, and *Larsia* were all dominant predators at our sites, and are well suited to occupying both intermittent and perennial streams. Members of the subfamilies Ceratopogoninae and Tanypodinae generally have flexible life cycles and are able to survive in both running waters and damp habitat (McAlpine et al. 1981). Of the 21 western species of *Sweltsa*, only the lifecycle of *S.fidelis* has been fully explained (Stewart and Stark 2002). According to Dieterich and Anderson (1995), *S.fidelis* that occupy western Oregon temporary streams have a complex two-year lifecycle; it includes egg hatch with the onset of flow in late autumn, growth of nymphs to medium size by summer, survival through summer drought probably under moist sections in the hyporheic zone, then resumption of growth in autumn, and synchronous emergence by spring of the second year. Lifecycles of eastern species of *Sweltsa* are also reported as two-year cycles with evidence of egg diapause, and the majority of nymphal growth occurring during the second summer prior to emergence (Stewart and Stark 2002). The high density of *Sweltsa* at our sites could have coincided with synchronous spring emergence and preceded the burrowing of immature nymphs into the hyporheic zone. In fact, we observed the highest rates of emergence of *Sweltsa* from our intermittent sites in spring prior to when these streams ceased flowing in the summer (Chapter 2).

Because they were subject to periodic drying, we predicted that intermittent streams would have lower richness of aquatic insects than perennial streams and would contain specially adapted taxa. Commonly cited reasons explaining why fewer benthic species occur in temporary versus permanent systems involve reduced colonization or survival by species typical of permanent habitats as temporary habitats dry (Williams 1996). Following our prediction, there was lower taxa richness at intermittent sites compared to perennial sites. While the majority of

taxa, 72%, were common to both intermittent and perennial sites, we also found taxa that were unique to either flow condition. Feminella (1996) found a similar trend in upland Alabama streams, with 75% of taxa ubiquitous across a gradient of flow permanence. Similarly in New York, the majority of taxa in intermittent streams were common to perennial streams (Delucchi and Peckarsky 1989).

Dieterich and Anderson (2000) scored species they found in Oregon headwaters as obligatory or facultative to either permanent or summer-dry streams. From our generic-level identification of 9 taxa unique to our intermittent sites (Table 3.5), *Holorusia* may be an obligate inhabitant of temporary waters and *Paraleuctra* may be facultative to both intermittent and perennial streams. A review of existing literature on the life histories of genera absent evaluations by Dieterich and Anderson (2000), revealed that while those taxa may not be obligate to temporary waters, many were well suited to the conditions. *Helichus*, *Dysmicohermes*, and *Philocasca* have the ability to survive in low water conditions in substrates ranging from moist sand (*Helichus*; Merritt and Cummins 1996), moist leaf litter on the forest floor (*Philocasca*; Anderson 1976), to dry streambeds (Coryalidae; Merritt and Cummins 1996). *Cryptochia* and *Nerophilus californicus* are commonly found in very small streams. *Cryptochia* have also been found in seepage areas and spring runs, and *N.californicus* has been collected from organic matter on sandy substrates of small streams (Anderson 1976). Compared to taxa in perennial streams, unique taxa in the intermittent streams were highly localized.

The majority of the 40 taxa unique to our perennial sites were either not assigned scores in Dieterich and Anderson (2000) or had insufficiently detailed life histories in the literature; therefore it is uncertain whether many of these taxa, including 19 genera of midges, have life histories unsuitable for surviving the annual cessation of surface flow at intermittent sites. There were scores for three of the 40 taxa: *Baetis spp.* were either obligate or facultative to perennial streams, and *Chelifera sp.* and *Glutops sp.* were inhabitants of both permanent and summer-dry streams (Dieterich and Anderson 2000). In benthic samples, *Baetis* was unique to our perennial streams and collected at 7 of the 13 perennial sites. Their distribution suggests they were obligate

to our perennial streams; however, we did collect a few *Baetis* emerging from one intermittent stream (Appendix B; Table B1). Species level identification would help determine if there were differences in distribution of *Baetis* spp. based on flow duration. A review of existing literature revealed that *Antocha* and *Neophylax* also appeared obligate to perennial streams. *Antocha* (McAlpine et al. 1981) and *Neophylax* (Anderson 1976) are only found in freshwater, particularly in rapidly flowing streams. While some eastern species of *Neophylax*, such as *N. autumnis*, have utilized a life history incorporating aestivation as pre-pupae over the summer and emergence in fall to adapt to summer-dry streams, none of the Oregon species are known to occur in temporary streams (Anderson 1976). Taxa richness in our study streams was consistent with other studies that documented both higher richness in perennial streams than intermittent streams, and many taxa common to both permanent and temporary waters (Feminella 1996; Williams 1996; Muchow and Richardson 1999).

To optimize the potential for detecting differences in community composition tied to flow-duration and/or harvest-condition, our study streams were within close proximity to each other and most catchments drained into North Fork of the Alsea River. We expected flow duration would be a stronger influence than harvest class on overall macroinvertebrate assemblage. However, assemblages at perennial-forested sites were distinctive from others, and most communities at perennial-clearcut sites were more similar to those at intermittent-clearcut and intermittent-forested sites. Intermittent stream macroinvertebrate assemblages were highly similar between clearcut and forested harvest conditions. In the smaller set of seven headwaters regionally similar to ours, Dieterich (1992) found a stronger influence on benthic community composition by flow-duration than by open- or closed-canopy. He attributed this finding primarily to one species, the beetle *Hydraena vandykei*, abundant at one ephemeral stream that transversed a meadow. We detected broader assemblage differences in perennial streams between clearcut and forested harvest conditions based on overall community structure rather than any one taxon.

In this study, mean substrate diameter, elevation, mean water temperature, catchment area, and stream channel dimensions were more highly correlated to the community composition than any parameters associated with reduced canopy, such as stream cover or stand age. The perennial-clearcut streams that showed the least similarity to the macroinvertebrate communities of other logged streams (P-CUT21 and P-CUT22) had catchment area, elevation, water temperature, and channel dimensions more similar to perennial-forested sites. These two streams may not have retained fine sediments after logging activities because their larger drainage areas could provide flushing power to transport smaller-diameter substrate to downstream reaches.

We used three methods to examine the relationships of individual taxa to flow-duration and harvest-condition: unique taxa lists (Table 3.5), correlations with NMS-ordination axes (Table 3.7), and indicator species analyses (Table 3.8). Observations of unique taxa produced a presence/absence list that documented those taxa collected only at perennial or intermittent sites. NMS-ordination analyses and Spearman correlations described gradient in physical habitat and taxa distribution. Indicator species analyses were based on individual taxon's consistency and exclusivity to a harvest-condition or flow-duration group, rather than any overall community patterns. The majority of the 49 taxa unique to a flow-duration class were rarely collected; only 10 of these taxa were correlated to NMS-axes primarily to perennial sites. Four of the unique taxa, the mayflies *Baetis*, *Cinygmula*, *Epeorus*, and *Ironodes*, occurred at more than half of the perennial sites, had significant positive correlations to NMS-ordination axes, and were indicator species for perennial sites. Taxa negatively correlated with NMS-axes had higher densities at intermittent-forested, intermittent-clearcut, and perennial-clearcut sites with finer substrate and warmer temperatures than positively correlated taxa. Indicator species analyses were complimentary to trends observed in NMS-analyses: several negatively correlated taxa were indicators for clearcut or intermittent sites, and several positively correlated taxa were indicators for perennial sites. However, indicator species analyses also allowed us to examine taxa that

were not strongly correlated with NMS-axes; in particular taxa that had significant percent perfect indication for forested harvest-condition.

In the Central Oregon Coast Range, intermittent headwater streams harbor many of the same taxa as perennial streams. Within flow-classes, aquatic macroinvertebrate assemblages in perennial streams appear to be affected by clearcut logging to a higher degree than intermittent streams. Unlike the Cascade streams that had volcanic parent material and were generally poor in fine sediment that Murphy et al. (1981) and Hawkins et al. (1982) studied, these Oregon Coast Range streams had sedimentary parent material and abundant sources of fines. Contrasting with observations by Murphy et al. (1981) and Hawkins (1982), the benthic communities in our study streams may be influenced to a stronger degree by changes in substrate composition associated with timber harvest than by loss of canopy-cover. Intermittent streams, which generally experience fewer flushing events and accumulate finer substrates than perennial streams, may be affected to a lesser degree by any sedimentation caused by logging activity. Under both clearcut and forested harvest conditions, flow-duration is an important factor influencing densities of aquatic macroinvertebrates and functional composition in the headwater streams we studied in the Central Oregon Coast Range.

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Chapter 4

Synthesis and Conclusions

Janel L. Banks

Small streams are disappearing from the landscape through human activities connected to agriculture, forestry, urban and residential development, and mining (Meyer and Wallace 2001). Changes in headwater streams have the potential to alter the dynamics of entire catchments as they feed all downstream reaches. Despite their ecological significance, headwater streams are often unprotected and left vulnerable to anthropogenic activities affecting the landscape. Moore and Richardson (2003) noted growing concern about effects of forest harvesting on small streams, which have been neglected by researchers compared to larger, downstream reaches. Most studies describing impacts of forest management on macroinvertebrate assemblages focus on larger, perennially flowing streams, ignoring impacts on the many headwater streams that experience drying or become intermittent during summer months as well as their potential downstream impacts. This thesis addressed concerns regarding the impacts of timber harvest on the macroinvertebrate fauna in perennial and summer-dry headwater streams in the Central Oregon Coast Range. My project provides a unique perspective among existing studies because of the small size of the catchment areas and channel dimensions of the streams studied, the number of sites, and the inclusion of both flow duration and harvest condition.

The important findings from the macroinvertebrate emergence component of this research (Chapter 2) were that community assemblages and abundances of emergent aquatic macroinvertebrates differed between clearcut and forested harvest conditions (Table 4.1). Regardless of the season sampled, more aquatic insects emerged from streams in clearcut catchments than from streams flowing through forested catchments. Through all seasons, more Diptera and Trichoptera emerged from streams whose riparian vegetation had been removed through timber harvest within a year of sampling. Taxa richness was higher at clearcut sites when compared to forested sites, regardless of flow duration. The functional composition differed between clearcut and forested streams, with more collector-filterers emerged from clearcut sites compared to forested sites (Table 4.1).

Table 4.1. Summary of patterns in benthic aquatic macroinvertebrate densities and adult aquatic macroinvertebrate emergence rates under different combinations of flow duration (intermittent and perennial) and harvest condition (clearcut and forested).

	Benthic	Emergence
<u>Taxa Metrics</u>		
Taxa Richness	Perennial > Intermittent	Clearcut > Forested
Evenness	No Differences	No Differences
Shannon-Wiener Diversity	No Differences	No Differences
Total Aquatic Insects	Intermittent > Perennial	Clearcut > Forested
<u>Orders</u>		
Ephemeroptera	No Differences	No Differences
Plecoptera	No Differences	Intermittent > Perennial ²
Trichoptera	Intermittent > Perennial	Clearcut > Forested
Diptera	No Differences	Clearcut > Forested
Non-Insects	No Differences	Not Applicable
<u>Functional Feeding Group</u>		
Collector-Filterer	Intermittent > Perennial	Clearcut > Forested; Inter. > Per. ¹
Collector-Gatherer	Intermittent > Perennial	No Differences
Scraper	No Differences	No Differences
Shredder	No Differences	No Differences
Predator	Intermittent > Perennial	No Differences

¹ = Summer Only; ² = Spring Only

Channel dimensions, substrate composition, and riparian vegetation were important controls on emergent macroinvertebrate community patterns in both intermittent and perennial headwater streams in each season. While our perennial sites shared similar lithology, clearcut sites had finer substrates than forested sites suggesting sedimentation through increased erosion and/or retention capacity from in-stream wood contributed by timber harvest. We found high correlations with measurements characterizing canopy cover and substrate composition, indicating that canopy reduction and substrate composition are both important influences on emergent macroinvertebrate communities in the studied headwaters.

In contrast to emergence patterns, benthic aquatic macroinvertebrates densities differ more between intermittent and perennial flow-duration than between harvest conditions (Chapter 3; Table 4.1). The total benthic density and densities of Trichoptera were higher at summer-dry

streams compared to perennially flowing streams. Most taxa found in intermittent streams were also found in perennial streams, but perennial streams supported more taxa that were reflected in higher taxa richness at these sites. Functional composition was also different between intermittent and perennial sites, with higher densities of collectors and predators at intermittent sites.

Benthic macroinvertebrate communities were highly similar among intermittent streams, regardless of harvest condition. Perennial-forested sites and perennial-clearcut sites with cooler mean water temperature and coarse substrate had distinctive community patterns from those at intermittent-clearcut, intermittent-forested, and the perennial-clearcut sites with predominantly fine substrates. Mean substrate diameter, elevation, mean water temperature, catchment area, and stream channel dimensions were more highly correlated to benthic community composition than any parameters associated with reduced canopy, such as stream cover or stand age. Benthic macroinvertebrates in perennial Oregon Coast Range headwater streams may be influenced to a stronger degree by changes in substrate composition resulting from timber harvest than loss of canopy-cover. Intermittent streams, which generally experience fewer flushing events and accumulate finer substrates than perennial streams, may be affected to a lesser degree by sedimentation caused by logging activity.

My emergence sampling took snapshots of the adult macroinvertebrates emerging during three different seasons. Surber sampling captured benthic taxa that were not collected through emergence trapping, especially non-insects. Both sampling methods captured aquatic insect taxa that were not collected by the opposing method (Table 4.2). Despite variation of the taxa collected through different sampling methods, there were some observations that were similar for both emergent and benthic assemblages (Table 4.1). Plecoptera occurred at higher densities in the benthos and emerged at higher rates at intermittent streams, especially in the spring. Collector-filterers had higher densities in the benthos of intermittent streams, and emerged at higher rates from intermittent than perennial streams especially in the summer. In these study

streams, substrate composition, channel dimensions, and water temperature influenced both benthic and emergent community patterns.

Table 4.2. Taxa collected only in benthic sampling or in emergence traps.

Unique to Benthic	Unique to Emergence
<u>Coleoptera</u>	<u>Coleoptera</u>
<i>Acneus</i>	Hydrophilidae
<i>Helichus</i>	Noteridae
<i>Heterlimnius</i>	<u>Diptera</u>
<i>Zaitzevia</i>	<i>Clinocera</i>
<i>Anchyteis</i>	Ephydriidae
<u>Diptera</u>	<i>Dolichocephala</i>
<i>Oreothalia</i>	Dolichopodidae
<i>Oreogeton</i>	<i>Hemerodromia</i>
<i>Glutops</i>	<i>Neoplasta</i>
<u>Plecoptera</u>	Ptychopteridae
<i>Calinueria</i>	<i>Potandyderus</i>
<i>Doroneuria</i>	<u>Plecoptera</u>
<u>Trichoptera</u>	<i>Megaleuctra</i>
<i>Anagapetus</i>	<i>Perlomyia</i>
<i>Cryptochia</i>	<i>Podmosta</i>
<i>Nerophilus californicus</i>	<u>Trichoptera</u>
<u>Megaloptera</u>	<i>Glossosoma</i>
<i>Dysmicohermes</i>	<i>Hydroptila</i>
<u>Odonata</u>	<i>Oligophlebodes</i>
<i>Cordulegaster</i>	<i>Paleagapetus</i>
	<i>Polycentropus</i>

Several important questions arose from combining the emergent and benthic components of this thesis. The higher emergence of aquatic macroinvertebrates from clearcut sites than forested sites in all seasons suggest that either food quality and/or food quantity is higher under logged conditions. The relative abundance, density, and emergence rate of scrapers did not usually differ between any combination of flow-duration or harvest-condition but that does not negate an increase in periphyton growth following logging. Efforts to document food quality and quantity in these streams could include measures of mass and the C:N ratios of periphyton and FPOM. Year-round continuous emergence sampling and repeated benthic sampling would

provide more information about aquatic macroinvertebrate fauna in these headwaters and help provide a comprehensive understanding of their life histories. The contribution of the adult aquatic macroinvertebrates to the terrestrial food web is also of interest (Nakano and Murakami 2001). It is important to explore how subsidies between aquatic and terrestrial systems may be influenced by clearcut logging of headwater catchments. Drift sampling at the mouths of these headwaters would help in assessing the impacts of logging on downstream reaches and potentially on salmonid populations (Piccolo and Wipfli 2002; Wipfli and Gregovich 2004).

Though random selection of study streams was not possible, the fully crossed two-factor design allowed me to describe trends in emergent and benthic macroinvertebrate assemblages across classes of flow-duration (intermittent and perennial) and harvest-condition (clearcut and forested). Correlations of emergent and benthic macroinvertebrate communities with the measured environmental gradients were suggestive that reduced canopy cover and substrate composition are influential factors. Reduction in canopy is a direct result of tree harvest and several previous studies have documented finer streambed substrates after logging and/or road building when sufficiently wide riparian buffers are not left intact (e.g. Brown and Krygier 1970; Moring and Lantz 1975; Iwamoto et al. 1978; Gibbons and Salo 1973; Murphy et al. 1981; Hall et al. 1987). My observational study provides evidence that current timber harvesting practices impact emergent and benthic macroinvertebrate assemblages of perennial and intermittent headwater streams in the Central Oregon Coast Range immediately after harvest. My thesis also examined fauna of intermittent streams, which have been largely ignored. I documented similar benthic and emergent assemblages in summer-dry and perennial streams, and the influences of timber harvest on the communities in these intermittent streams. Research opportunities remain to explore how forestry affects the physicochemical characteristics and flow regime of headwaters, the pathways through which macroinvertebrate communities are subsequently affected, and the potential impacts on both terrestrial systems and downstream reaches.

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APPENDICES

APPENDIX A: SITE DESCRIPTIONS

Table A1. Definitions of environmental variables compiled for analyses.

	Unit	Definition
<u>Stream Variables</u>		
Active Channel Width	m	Reach average of the active channel width
Bankfull Width	m	Reach average of the bankfull width
Sand & Fines	%	Substrate in size classes < sand (≤ 2 mm)
Small Gravel, Sand, & Fines	%	Substrate in size classes \leq fine gravel (≤ 16 mm)
Coarse Substrate	%	Substrate in size classes > fine gravel (≥ 16 mm)
Organics	%	Substrate composed of wood or organic detritus
Mean Substrate Diameter	-	Log_{10} of geometric mean substrate diameter (mm)
Stream Cover	%	Cover from vegetation and topography
Fast-Water Habitat Type	%	Falls+Cascades+Rapids+Riffles
Slow-Water Habitat Type	%	Pools (All Types) + Glides
Summer Water Temperature	$^{\circ}\text{C}$	Mean water temperature (August-September)
Fall Water Temperature	$^{\circ}\text{C}$	Mean water temperature (October-November)
Spring Water Temperature	$^{\circ}\text{C}$	Mean water temperature (March-April)
Mean Water Temperature	$^{\circ}\text{C}$	Mean water temperature (August-April)
Slope	%	Slope of stream reach
Elevation	m	Elevation of site
Catchment Area	ha	Area draining into stream.
<u>Riparian Variables</u>		
Big Trees Canopy	%	Canopy (>5m high): cover by trees >0.3 DBH
Small Trees Canopy	%	Canopy (>5 m high): cover by trees ≤ 0.3 DBH
Non-Woody Understory	%	Mid-layer (0.5 to 5 high): herbaceous cover
Woody Understory	%	Mid-layer (0.5 to 5 high): woody cover
Non-Woody Ground Cover	%	Ground-layer (<0.5 m): woody cover
Woody Ground Cover	%	Ground-layer (<0.5 m): herbaceous cover
Slash	%	Ground-layer (<0.5 m): logging debris (slash)
Stand Age	yrs	Years since last logged

Table A2. Location and physical habitat characteristics of the 20 headwater study sites.

Harvest Condition	I-CUT12	I-CUT36	I-CUT37	P-CUT10	P-CUT15	P-CUT16	P-CUT17	P-CUT21	P-CUT22	P-CUT25
	Clearcut Intermittent	Clearcut Intermittent	Clearcut Intermittent	Clearcut Perennial	Clearcut Perennial	Clearcut Perennial	Clearcut Perennial	Clearcut Perennial	Clearcut Perennial	Clearcut Perennial
Flow Duration	458045	455829	455805	455816	457651	456582	456582	460479	460580	455620
UTM 10 Easting	4921710	4917728	4917980	4921725	4922837	4920220	4920256	4919824	4919819	4914497
UTM 10 Northing	0.3	1.2	1.6	1.2	0.9	1.1	0.7	2.7	3.0	2.0
Active Channel Width (m)	1.0	1.5	2.0	3.5	1.0	1.5	1.3	3.0	3.0	2.5
Bankfull Width (m)	64	90	86	20	52	75	87	50	51	90
Sand & Fines (%)	64	92	90	33	69	75	87	64	65	90
Small Gravel, Sand, & Fines (%)	0	4	4	20	13	5	0	34	29	0
Coarse Substrate (%)	36	4	6	47	18	20	13	2	6	10
Organics (%)	-2.11	-1.90	-1.80	0.10	-0.88	-1.79	-1.54	0.38	0.22	-2.11
Mean Substrate Diameter	2	48	48	37	24	17	4	52	12	0
Summer Stream Cover (%)	11	24	42	37	22	21	12	57	17	3
Fall Stream Cover (%)	0	17	26	23	5	14	11	52	11	0
Spring Stream Cover (%)	100	56	33	100	61	100	78	80	82	11
Fast-Water Habitat Type (%)	0	11	11	0	39	0	22	10	18	89
Slow-Water Habitat Type (%)	11.0	11.9	12.6	11.7	12.5	12.3	11.5	11.2	13.0	12.6
Summer Water Temperature (°C)	8.7	10.4	10.3	9.7	10.1	10.3	10.0	9.2	8.5	10.1
Fall Water Temperature (°C)	8.8	10.1	9.9	9.1	9.6	9.9	9.7	7.8	8.1	10.3
Spring Water Temperature (°C)	9.8	10.6	10.6	9.5	10.1	9.7	10.1	8.6	8.4	10.4
Mean Water Temperature (°C)	33	14	15	33	30	34	21	12	15	4
Slope (%)	294	146	173	519	332	292	300	540	571	132
Elevation (m)	2.3	6.0	3.0	3.7	4.5	4.6	4.4	18.0	33.0	16.0
Catchment Area (ha)	0	0	5	3	0	0	0	3	0	0
Big Trees Canopy (%)	0	3	3	0	0	0	0	15	5	0
Small Trees Canopy (%)	25	25	25	5	58	25	25	5	25	25
Non-Woody Understory (%)	5	3	5	5	15	5	5	5	5	5
Woody Understory (%)	25	88	58	25	58	58	25	25	15	56
Non-Woody Ground Cover (%)	5	15	5	5	5	25	5	5	5	5
Woody Ground Cover (%)	73	58	88	88	58	58	58	25	58	58
Slash (%)	0	1	1	0	0	0	0	0	0	1
Stand Age (yrs)										

Table A2 (Continued). Location and physical habitat characteristics of the 20 headwater study sites.

	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
Harvest Condition	Forested Intermittent	Forested Intermittent	Forested Intermittent	Forested Intermittent	Forested Perennial	Forested Perennial	Forested Perennial	Forested Perennial	Forested Perennial	Forested Perennial
Flow Duration	456134	456858	458157	459764	456307	455971	455911	461030	459182	462723
UTM 10 Easting	4917957	4918075	4917987	4919793	4913043	4913378	4913443	4920576	4919993	4922023
UTM 10 Northing	1.5	1.0	1.0	2.3	1.4	2.1	1.5	2.6	3.3	2.8
Active Channel Width (m)	1.8	1.5	1.5	4.0	1.5	2.6	1.8	3.0	4.0	3.0
Bankfull Width (m)	92	85	74	65	36	46	56	14	19	30
Sand & Fines (%)	92	90	81	82	58	63	64	52	33	51
Small Gravel, Sand, & Fines (%)	0	5	12	15	36	34	29	46	65	44
Coarse Substrate (%)	8	5	7	3	6	3	7	2	2	5
Organics (%)	-2.06	-1.63	-1.28	-0.76	0.58	0.13	-0.23	0.96	1.32	0.55
Mean Substrate Diameter	97	96	95	99	96	95	93	91	89	93
Summer Stream Cover (%)	90	95	100	99	92	95	93	95	99	96
Fall Stream Cover (%)	92	91	95	99	83	90	94	93	99	94
Spring Stream Cover (%)	40	40	100	0	73	55	81	91	100	64
Fast-Water Habitat Type (%)	50	30	0	9	27	36	19	9	0	36
Slow-Water Habitat Type (%)	13.0	13.0	12.5	10.9	12.3	12.7	12.7	11.4	11.4	12.9
Summer Water Temperature (°C)	10.9	10.0	9.3	9.2	9.4	9.7	9.1	8.7	7.6	9.3
Fall Water Temperature (°C)	9.5	9.5	9.0	7.5	9.0	9.4	9.2	8.8	7.8	8.9
Spring Water Temperature (°C)	10.3	10.3	9.4	8.6	9.5	10.1	9.7	8.6	8.2	9.8
Mean Water Temperature (°C)	7	13	42	4	18	6	20	30	40	11
Slope (%)	181	242	414	564	226	145	169	489	615	345
Elevation (m)	1.9	3.4	6.0	3.4	18.0	16.0	8.8	16.0	4.1	55.0
Catchment Area (ha)	25	5	5	25	25	25	25	25	5	25
Big Trees Canopy (%)	25	25	58	25	25	25	25	25	88	25
Small Trees Canopy (%)	88	88	58	25	88	88	88	58	0	88
Non-Woody Understory (%)	5	25	5	25	25	25	5	25	0	5
Woody Understory (%)	88	88	73	88	88	88	88	88	5	88
Non-Woody Ground Cover (%)	5	5	5	25	5	5	5	25	0	15
Woody Ground Cover (%)	0	0	0	0	0	0	0	0	0	15
Slash (%)	62	62	52	62	36	36	36	62	34	52
Stand Age (yrs)										

APPENDIX B: EMERGENCE AND BENTHIC DATA

Table B1. Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa	Taxa Code	I-CUT12			I-CUT36			I-CUT37			P-CUT10		
		Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Ephemeroptera</u>													
Ameletidae	<i>Ameletus</i>	0.29	0.00	0.19	0.00	0.00	0.10	0.24	0.00	0.10	0.14	0.00	0.29
Baetidae	<i>Baetis</i>	0.34	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Dipheter hageni</i>	0.05	0.00	0.19	0.00	0.00	0.24	0.19	0.00	0.00	0.10	0.10	0.32
	sp.	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Ephemerellidae	<i>Ephemerella/Serrat</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heptageniidae	<i>Cinygna</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Cinygmula</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Epeorus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Ironodes</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	sp.	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
	<i>Paraleptophlebia</i>	3.46	0.29	0.05	0.53	0.00	0.43	1.59	0.00	0.62	0.77	0.10	0.10
<u>Plecoptera</u>													
Chloroperlidae	<i>Bisancora</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Sweltsa</i>	0.00	0.00	0.29	0.00	0.00	0.43	0.00	0.00	0.91	0.00	0.00	0.27
Leuctridae	<i>Despaxia augusta</i>	0.05	1.68	0.00	0.10	0.58	0.00	0.77	0.59	0.00	0.10	0.05	0.00
	<i>Megaleuctra</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Moselia infuscata</i>	0.00	0.00	3.27	0.00	0.00	3.60	0.00	0.00	0.82	0.00	0.00	5.99
	<i>Paraleuctra</i>	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32
	<i>Perlomyia</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nemouridae	<i>Malenka</i>	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Ostrocerca</i>	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.86	0.00	0.00	0.00
	<i>Podmosta</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	<i>Soyedina</i>	1.06	0.10	0.38	0.05	0.00	0.77	0.34	0.06	0.14	0.62	0.00	0.30
	<i>Zapada</i>	0.00	1.63	0.00	0.00	0.53	0.00	0.00	0.10	0.00	0.05	1.20	0.06
	sp.	0.10	0.00	0.05	0.10	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Peltoperlidae	<i>Yoraperla</i>	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-CUT15			P-CUT16			P-CUT17			P-CUT21			P-CUT22			P-CUT25			
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	
<u>Ephemeroptera</u>																			
ameame	0.00	0.00	0.24	0.00	0.00	0.14	0.00	0.00	0.05	0.05	0.00	0.58	0.05	0.00	0.24	0.05	0.00	0.14	
baetis	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.05	0.38	0.34	0.26	0.85	0.00	0.00	0.00	
diphtr	0.05	0.00	0.05	0.05	0.19	0.00	0.00	0.05	0.14	0.29	0.00	0.10	0.82	0.14	0.38	0.38	0.67	1.11	
baetsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	
ephmrl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	
hpciny	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.05	
hpcinm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.13	0.00	0.00	0.00	
heptep	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
hepiro	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.48	0.00	0.00	0.19	0.00	0.00	0.00	
heptsp	0.00	0.00	0.00	0.10	0.00	0.10	0.14	0.00	0.00	0.00	0.00	0.24	0.10	0.00	0.10	0.00	0.00	0.00	
leppar	2.69	0.14	0.53	3.08	0.72	0.58	1.01	0.91	0.05	0.29	0.00	0.00	0.05	0.00	0.05	1.73	0.10	0.29	
<u>Plecoptera</u>																			
chlbis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
chiswl	0.00	0.00	0.14	0.00	0.00	0.67	0.05	0.00	0.14	0.00	0.00	0.05	0.00	0.00	0.13	0.00	0.00	0.00	
desaug	0.00	0.43	0.00	0.00	0.14	0.00	0.19	0.34	0.00	0.19	0.10	0.00	0.19	0.00	0.00	0.00	0.00	0.00	
lcmega	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	
lcnose	0.00	0.00	2.50	0.00	0.00	1.15	0.00	0.00	0.48	0.00	0.00	0.14	0.00	0.00	0.64	0.00	0.00	0.91	
lcpara	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.11	0.00	0.00	0.00	
lcpilo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	
nmmlal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	0.05	0.05	0.00	0.38	0.00	0.00	0.00	0.00	0.53	1.54	
nmrost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
nmrpod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
nmrsoy	0.67	0.00	0.24	0.62	0.14	1.01	2.79	0.10	0.05	0.38	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.05	
nmrizap	0.10	3.60	0.00	0.10	0.24	0.00	0.00	5.67	0.00	0.05	2.69	0.24	0.00	0.10	0.37	0.00	0.34	0.00	
nmrsp	0.00	0.10	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
pltyor	0.00	0.00	0.38	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.24	0.00	0.00	0.19	

*Taxa listed on page 92.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	I-FOR26			I-FOR28			I-FOR38			I-FOR40			P-FOR32		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Ephemeroptera</u>															
ameame	0.00	0.00	0.38	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00
baetis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
diphtr	0.53	0.58	1.06	0.05	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.10	0.14	0.05
baetsp	0.29	0.00	0.00	0.05	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.05
ephmrl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hpciny	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
hpcinm	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
heptep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hepiro	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
heptsp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
leppar	4.37	0.14	2.11	1.25	0.00	2.26	1.06	0.00	0.00	0.00	0.00	0.43	3.36	0.00	0.58
<u>Plecoptera</u>															
chlbis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
chlswl	0.00	0.00	1.39	0.00	0.00	6.10	0.00	0.00	0.38	0.00	0.00	0.74	0.00	0.00	0.00
desaug	0.10	0.29	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.24	0.10	0.05
lcmega	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
lcmose	0.00	0.00	2.16	0.00	0.00	0.62	0.00	0.00	4.04	0.00	0.00	0.21	0.00	0.00	0.24
lcpara	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
lcpilo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nmrml	0.10	0.00	1.92	0.00	0.00	1.87	0.00	0.05	0.00	0.00	0.00	2.67	0.00	0.00	0.00
nmrost	0.00	0.00	0.29	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	2.59	0.00	0.00	0.00
nmrpod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nmrsoy	0.19	0.05	0.29	0.82	0.00	0.67	0.86	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.00
nmrzap	0.05	0.00	0.00	0.00	0.05	0.00	0.00	1.59	0.00	0.00	0.00	0.05	0.00	0.00	0.19
nmrsp	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
pltyor	0.00	0.00	0.14	0.00	0.00	0.67	0.00	0.00	0.62	0.00	0.00	0.00	0.00	0.00	0.00

*Taxa listed on page 92.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-FOR33			P-FOR34			P-FOR35			P-FOR41			P-FOR42		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Ephemeroptera</u>															
ameame	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
baetis	0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.24	0.00	0.05	0.05	0.00	0.00	0.00	0.00
diphtr	0.00	0.14	0.00	0.30	0.14	0.00	0.05	0.00	0.00	0.24	0.00	0.53	0.38	0.05	0.10
baetsp	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	0.00
ephmrl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hpciny	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
hpcinm	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
heptep	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hepiro	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.10	0.14	0.00	0.00
heptsp	0.00	0.00	0.19	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
leppar	0.00	0.00	0.14	1.28	0.14	0.00	0.10	0.00	0.10	0.53	0.00	0.05	0.53	0.00	0.34
<u>Plecoptera</u>															
chlbis	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
chlswl	0.00	0.00	0.19	0.00	0.00	0.26	0.00	0.00	0.10	0.00	0.00	0.10	0.00	0.00	0.00
desaug	0.00	0.10	0.00	0.06	0.00	0.00	0.19	0.19	0.00	0.00	0.00	0.00	0.00	0.10	0.00
lcmega	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
lcmose	0.00	0.00	0.14	0.00	0.00	0.93	0.00	0.00	0.24	0.00	0.00	3.03	0.00	0.00	0.00
lcpara	0.00	0.00	0.14	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
lcprio	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nmmal	0.00	0.00	0.24	0.00	0.00	0.00	0.43	0.00	0.00	0.05	0.00	0.00	0.10	0.00	0.29
nmrost	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nmrpod	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
nmrsoy	0.10	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.05	1.06	0.00	0.34	0.05	0.00	0.00
nmrzap	0.00	0.05	0.05	0.00	0.10	0.00	0.00	0.91	0.38	0.00	0.48	0.05	0.05	0.19	0.50
nmrsp	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.05	0.00	0.00	0.00
plyor	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.29

*Taxa listed on page 92.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa	Taxa Code	I-CUT12			I-CUT36			I-CUT37			P-CUT10			
		Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	
Perlotidae	procal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	proiso	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	perisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trichoptera														
Brachycentridae	Micrasema	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.11
Glossomatidae	Glossosoma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goeridae	Goera/Goeracea	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydropsychidae	Homoptecta	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34
	Parapsyche	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hydroptilidae	Hydroptila	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
	Palaeagapetus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lepidostomatidae	Lepidostoma	1.83	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.29	0.00	0.00	0.00
Limnephilidae	Chyranda centralis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
	Philocasca	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01
	Psychoglypha	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
	sp.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Philopotamidae	Dolophilodes	0.14	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Wormaldia	1.92	0.34	0.14	0.86	0.82	0.29	0.86	0.82	0.29	0.67	0.18	0.05	0.29
Polycentropodidae	Polycentropus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
Rhyacophilidae	Rhyacophila	0.19	0.00	0.10	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.18
Uenoidae	Neophylax	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Oligophlebodes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diptera														
Ceratopogonidae	cerato	1.49	0.05	0.00	1.59	0.00	0.00	1.59	0.00	0.00	1.68	0.00	0.62	0.34
Chironomidae	chiron	5.67	19.46	15.33	22.78	31.28	10.81	22.78	31.28	10.81	11.29	9.43	4.47	8.22
Dixidae	dixida	0.58	0.14	0.00	0.00	0.38	0.14	0.00	0.38	0.14	0.67	0.35	0.00	0.06
Dolichopodidae	dolich	0.00	0.00	0.00	0.58	0.00	0.00	0.58	0.00	0.00	0.48	0.06	0.05	0.00
Empididae	empchf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	empcln	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Clinocera													

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-CUT15			P-CUT16			P-CUT17			P-CUT21			P-CUT22			P-CUT25			
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	
<u>Plecoptera</u>																			
procal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
proiso	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
perisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	
<u>Trichoptera</u>																			
micsma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
glsjgls	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.10	0.19	0.00	0.48	0.00	0.00	0.00	
goerid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
hyhpca	0.00	0.00	0.19	0.00	0.00	0.38	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
hypara	0.05	0.00	0.24	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.14	0.00	0.05	0.00	0.00	0.00	
hydhyd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.05	0.10	
hydpal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
leplep	2.35	0.00	0.00	3.17	0.05	0.00	2.31	0.19	0.00	0.38	0.00	0.00	0.19	0.00	0.00	0.10	0.00	0.00	
limchy	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
limphi	0.00	0.19	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	
limpsy	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	
limunk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
phidol	0.00	0.00	0.29	0.29	0.14	0.38	0.10	0.05	0.10	0.05	0.05	0.00	0.05	0.06	0.06	0.00	0.00	0.00	
phiwor	0.05	0.00	0.00	0.38	0.38	0.14	1.06	0.91	0.43	0.29	0.24	0.19	1.06	0.42	0.19	0.14	0.43	0.24	
plycen	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
rhycha	0.10	0.00	0.00	0.05	0.00	0.00	0.19	0.00	0.00	0.05	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	
uenplx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
unoolg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
<u>Diptera</u>																			
cerato	2.16	0.19	0.10	1.87	0.48	0.34	1.49	0.86	0.00	0.24	0.29	0.00	0.00	0.00	0.00	1.25	0.05	0.00	
chiron	15.76	22.54	7.40	22.10	31.81	10.86	14.85	38.92	5.29	29.12	13.41	3.17	18.21	12.77	3.64	26.53	7.83	9.08	
dixida	0.29	0.14	0.00	1.06	0.34	0.00	0.19	0.58	0.00	0.14	0.10	0.00	0.19	0.00	0.00	0.19	0.05	0.05	
dolich	0.24	0.10	0.05	0.77	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06	0.19	0.00	
empchf	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	
empcfn	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.10	0.14	0.00	0.00	0.00	0.00	0.10	0.14	0.05	

*Taxa listed on page 96.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	I-FOR26			I-FOR28			I-FOR38			I-FOR40			P-FOR32		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Plecoptera</u>															
procal	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
proiso	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
perfsp	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
<u>Trichoptera</u>															
micsma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
glsgls	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
goerid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hyhpca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hypara	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hydhyd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hydpal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
leplep	0.00	0.00	0.05	0.05	0.00	0.29	0.29	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
limchy	0.00	0.00	0.00	0.05	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
limphi	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.05	0.00
limpsy	0.00	0.05	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
limunk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
phldol	0.00	0.00	0.00	0.05	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
phlwor	0.14	0.10	0.14	0.86	0.10	0.10	1.68	0.19	0.53	0.05	0.00	0.00	0.00	0.05	0.00
plycen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rhycha	0.05	0.00	0.00	0.14	0.00	0.10	0.00	0.05	0.00	0.05	0.00	0.00	0.00	0.00	0.00
uenplx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unoolg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<u>Diptera</u>															
cerato	0.62	0.00	0.10	0.43	0.00	0.00	0.67	0.00	0.05	0.58	0.00	0.00	2.50	0.00	0.00
chiron	8.65	3.89	3.75	5.43	2.50	10.24	8.12	5.67	3.32	7.35	3.94	1.92	3.32	4.18	0.62
dixida	0.86	0.48	0.10	1.11	0.10	0.00	0.43	0.24	0.14	0.14	0.10	0.00	0.29	0.05	0.00
dolich	0.05	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empchf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empcln	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Taxa listed on page 96.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-FOR33			P-FOR34			P-FOR35			P-FOR41			P-FOR42		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Plecoptera</u>															
procal	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
proiso	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
perisp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
<u>Trichoptera</u>															
micsma	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
glsgls	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.24
goetid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00
hyhpca	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hypara	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00
hydhyd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hydpal	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
leplep	0.10	0.00	0.00	1.27	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.00
limchy	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
limphi	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
limpsy	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
limunk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
phldol	0.00	0.00	0.05	0.00	0.00	0.06	0.05	0.00	0.14	0.00	0.00	0.00	0.14	0.00	0.00
phlwor	0.10	0.14	0.00	0.00	0.53	0.00	0.05	0.00	0.05	0.00	0.05	0.00	0.14	0.05	0.00
plycen	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
rhycha	0.00	0.00	0.10	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
uenplx	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
unoolg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<u>Diptera</u>															
cerato	0.19	0.00	0.00	0.86	0.00	0.00	0.24	0.10	0.00	0.00	0.00	0.00	0.05	0.00	0.00
chiron	1.54	6.44	1.39	2.90	7.93	0.54	8.75	5.38	2.98	0.00	0.00	5.72	5.33	3.89	5.25
dixida	0.19	0.10	0.00	0.18	0.05	0.00	0.58	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00
dolich	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
empchf	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empchl	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Taxa listed on page 96.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa	Taxa Code	I-CUT12			I-CUT36			I-CUT37			P-CUT10			
		Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	
Diptera														
Empididae	<i>Dolichocephala</i>	0.00	0.00	0.29	0.05	0.05	0.10	0.10	0.00	0.34	0.10	0.00	0.06	
	<i>Hemerodromia</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
	<i>Neoplasta</i>	0.00	0.05	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	
Ephydriidae		0.05	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	
Psychodidae		0.24	0.48	1.15	0.53	0.00	1.39	0.34	0.05	0.67	0.43	0.05	1.20	
Ptychopteridae		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Simuliidae		0.00	0.00	0.05	0.14	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	
Tanyderidae	<i>Protandyrus</i>	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Thaumaleidae	<i>Thaumalea</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Tipulidae		0.43	0.29	0.19	0.62	1.06	0.00	0.43	0.61	0.62	0.67	0.14	0.43	
Coleoptera														
Dytiscidae		0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Elmidae	<i>Lara</i>	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Hydrophilidae		0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	
Noteridae		0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-CUT15			P-CUT16			P-CUT17			P-CUT21			P-CUT22			P-CUT25			
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	
<u>Diptera</u>																			
empdol	0.05	0.05	0.34	0.05	0.10	0.10	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	
empned	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
empneo	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.14	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.24	0.00	
ephydr	0.10	0.00	0.05	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
psydrp	0.14	0.10	0.96	0.14	0.14	0.67	0.05	0.19	0.05	0.10	0.00	0.00	0.00	0.00	0.48	0.10	0.00	0.00	
ptycho	0.00	0.00	0.00	0.05	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00	
simuli	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.10	0.00	0.48	0.10	0.43	0.00	
tanpot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
thaura	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
tipuli	1.25	1.30	0.43	0.91	1.15	0.38	0.19	1.15	0.10	0.00	0.00	0.00	0.00	0.00	0.10	0.24	0.00	0.00	
<u>Coleoptera</u>																			
dytisc	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.24	0.05	0.00	
elmira	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
hyphil	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	
noteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

*Taxa listed on page 100.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	I-FOR26			I-FOR28			I-FOR38			I-FOR40			P-FOR32		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Diptera</u>															
empdol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
emphe	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empneo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ephydr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
psydip	0.19	0.00	0.14	0.19	0.00	0.43	0.00	0.00	0.00	0.14	0.00	0.00	0.10	0.00	0.00
ptycho	0.05	0.00	0.00	0.00	0.05	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
simuli	0.14	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00
tanpot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
thau	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
tipulli	0.24	0.05	0.10	0.82	0.38	0.72	0.77	0.05	0.05	0.53	0.00	0.19	0.19	0.00	0.00
<u>Coleoptera</u>															
dytisc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
elmira	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hyphil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
noteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Taxa listed on page 100.

Table B1 (Continued). Emergence rates of aquatic macroinvertebrates (individuals/m²/day) from the 20 headwater sites in summer, fall and spring.

Taxa Code*	P-FOR33			P-FOR34			P-FOR35			P-FOR41			P-FOR42		
	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring
<u>Diptera</u>															
empdol	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empheh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
empneo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ephydr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
psydip	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ptycho	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
simuli	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.14	0.00	0.00	0.06
tanpot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
thagma	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tipuli	0.00	0.00	0.00	0.14	0.10	0.19	0.10	0.00	0.00	0.05	0.05	0.00	0.05	0.00	0.00
<u>Coleoptera</u>															
dytisc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
elmira	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
hyphil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
noteri	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

*Taxa listed on page 100.

Table B2. Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa	Taxa Code	I-CUT12	I-CUT36	I-CUT37	P-CUT10	P-CUT15	P-CUT16	P-CUT17	P-CUT21
<u>Ephemeroptera</u>									
Ameletidae	Ameletus	20.8	0.0	69.4	50.0	138.9	8.3	0.0	58.3
Baetidae	Baetis	0.0	0.0	0.0	0.0	55.6	0.0	0.0	91.7
	<i>Dipheter hageni</i>	0.0	50.0	0.0	66.7	13.9	0.0	0.0	12.5
Ephemereilidae	<i>Drunella</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.5
	sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8
Heptageniidae	<i>Cinygma</i>	0.0	0.0	0.0	41.7	0.0	58.3	0.0	41.7
	<i>Cinygmula</i>	0.0	0.0	0.0	0.0	0.0	8.3	0.0	20.8
	<i>Epeorus</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	108.3
	<i>Ironodes</i>	0.0	0.0	0.0	0.0	41.7	0.0	5.6	33.3
Leptophlebiidae	<i>Paraleptophlebia</i>	83.3	83.3	694.4	195.8	347.2	183.3	33.3	58.3
<u>Plecoptera</u>									
Chloroperlidae	<i>Kathroperla</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7
	<i>Sweitsa</i>	208.3	116.7	333.3	112.5	69.4	58.3	16.7	116.7
Leuctridae	<i>Despaxia augusta</i>	20.8	8.3	250.0	0.0	111.1	0.0	0.0	0.0
	<i>Moselia infuscata</i>	520.8	266.7	583.3	108.3	583.3	225.0	166.7	529.2
	<i>Paraleuctra</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Malenka</i>	0.0	0.0	0.0	0.0	0.0	0.0	5.6	16.7
Nemouridae	<i>Ostrocerca</i>	0.0	0.0	0.0	0.0	0.0	58.3	0.0	0.0
	<i>Soyedina</i>	125.0	100.0	0.0	83.3	55.6	116.7	16.7	0.0
	<i>Zapada</i>	385.4	466.7	0.0	329.2	708.3	308.3	150.0	41.7
	sp.	0.0	0.0	27.8	0.0	0.0	0.0	0.0	0.0
Peltoperlidae	<i>Yoraperla</i>	458.3	0.0	0.0	58.3	277.8	66.7	11.1	162.5
Perlidae	<i>Calineuria</i>	0.0	8.3	0.0	4.2	0.0	0.0	0.0	0.0
	<i>Doroneuria</i>	0.0	0.0	0.0	16.7	0.0	0.0	0.0	0.0
	<i>Calliperla</i>	52.1	0.0	0.0	8.3	0.0	0.0	0.0	4.2
	<i>Isoperla</i>	52.1	0.0	0.0	8.3	0.0	50.0	0.0	0.0
	sp.	10.4	91.7	125.0	0.0	41.7	0.0	72.2	0.0
<u>Megaloptera</u>									
Corydalidae	<i>Dysmicohermes</i>	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
<u>Odonata</u>									
Cordulegastridae	<i>Cordulegaster</i>	0.0	0.0	13.9	0.0	13.9	8.3	44.4	0.0

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa Code*	P-CUT22	P-CUT25	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
<u>Ephemeroptera</u>												
ameame	22.2	33.3	52.1	41.7	0.0	291.7	3.3	11.1	9.6	8.3	0.0	8.3
baetis	408.3	0.0	0.0	0.0	0.0	0.0	116.7	27.8	0.0	62.5	0.0	37.5
diphtr	47.2	283.3	177.1	0.0	20.8	41.7	0.0	16.7	9.6	133.3	102.8	8.3
ephdru	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	4.2
ephmrl	0.0	0.0	0.0	0.0	0.0	12.5	0.0	0.0	0.0	0.0	5.6	0.0
hpciny	2.8	25.0	177.1	138.9	0.0	66.7	10.0	5.6	48.1	170.8	19.4	104.2
hpcinn	16.7	0.0	0.0	0.0	0.0	0.0	36.7	0.0	3.2	79.2	2.8	0.0
heptep	16.7	0.0	0.0	0.0	0.0	0.0	33.3	22.2	6.4	25.0	5.6	0.0
hepiro	25.0	0.0	0.0	0.0	0.0	0.0	43.3	11.1	3.2	0.0	0.0	0.0
leppar	16.7	291.7	677.1	680.6	229.2	408.3	93.3	255.6	96.2	16.7	69.4	245.8
<u>Plecoptera</u>												
chlkth	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	8.3	0.0	0.0
chloro	22.2	0.0	145.8	722.2	41.7	283.3	140.0	377.8	48.1	37.5	2.8	158.3
desaug	2.8	0.0	156.3	0.0	20.8	0.0	110.0	150.0	64.1	50.0	8.3	62.5
lciose	11.1	366.7	437.5	0.0	1770.8	16.7	50.0	166.7	230.8	45.8	175.0	204.2
lcpara	0.0	0.0	0.0	0.0	125.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
nrmml	0.0	116.7	166.7	55.6	83.3	45.8	83.3	450.0	157.1	91.7	8.3	200.0
nmrost	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
nrmsoy	0.0	0.0	0.0	27.8	0.0	12.5	0.0	0.0	16.0	37.5	2.8	0.0
nrmzap	0.0	133.3	0.0	208.3	854.2	0.0	26.7	105.6	19.2	37.5	33.3	45.8
nrmrsp	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
pityor	11.1	16.7	0.0	194.4	41.7	0.0	60.0	22.2	22.4	158.3	69.4	62.5
prlcal	0.0	0.0	0.0	0.0	0.0	0.0	3.3	38.9	0.0	0.0	0.0	12.5
prldor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	25.0	0.0	0.0
procal	0.0	25.0	0.0	0.0	20.8	279.2	0.0	0.0	0.0	0.0	0.0	0.0
proiso	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	58.3	0.0
perisp	0.0	0.0	406.3	97.2	145.8	0.0	16.7	22.2	125.0	91.7	0.0	50.0
<u>Megaloptera</u>												
mgadys	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<u>Odonata</u>												
odocor	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0

*Taxa listed on page 104.

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa	Taxa Code	I-CUT12	I-CUT36	I-CUT37	P-CUT10	P-CUT15	P-CUT16	P-CUT17	P-CUT21
<u>Trichoptera</u>									
Brachycentridae	Micrasema	10.4	0.0	0.0	0.0	13.9	0.0	0.0	0.0
Glossosomatidae	Anagapetus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5
Goeridae	Goeracea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hydropsychidae	Homoplectra	41.7	0.0	0.0	0.0	13.9	75.0	5.6	0.0
	Parapsyche	0.0	0.0	0.0	0.0	13.9	0.0	0.0	0.0
Lepidostomatidae	Lepidostoma	20.8	8.3	13.9	0.0	0.0	75.0	22.2	50.0
Limnephilidae	Cryptochia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Chyranda centralis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Philocasca	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Psychoglypha	20.8	33.3	166.7	8.3	13.9	8.3	16.7	0.0
	sp. (larva)	0.0	133.3	444.4	0.0	41.7	0.0	27.8	58.3
Odontoceridae	Nerophilus californicus	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0
Philopotamidae	Dolophilodes	31.3	0.0	0.0	0.0	0.0	58.3	0.0	8.3
	Wormaldia	72.9	241.7	13.9	29.2	13.9	66.7	16.7	0.0
Rhyacophilidae	Rhyacophila	10.4	41.7	0.0	20.8	13.9	50.0	5.6	12.5
Uenoidae	Neophylax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3
<u>Coleoptera</u>									
Dryopidae	Helichus	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0
Dytiscidae	Dytisc	0.0	25.0	27.8	0.0	0.0	0.0	5.6	0.0
Elmidae	Heterolimnius	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Lara	10.4	8.3	13.9	25.0	125.0	0.0	44.4	0.0
	Zaitzevia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	sp.	0.0	8.3	0.0	0.0	125.0	0.0	0.0	4.2
Psephenidae	Acneus	0.0	0.0	0.0	0.0	13.9	0.0	0.0	4.2
Ptilodactylidae	Anchyteis	20.8	0.0	0.0	8.3	0.0	0.0	27.8	4.2
<u>Diptera</u>									
Ceratopogonidae	Ceratopogoninae	395.8	150.0	277.8	95.8	194.4	166.7	100.0	33.3
	Forcipomyiinae	0.0	16.7	0.0	0.0	13.9	0.0	5.6	0.0
Chironomidae	Paratendipes sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chironomini	Polypedilum sp.	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m2) from the 20 headwater study sites.

Taxa Code*	P-CUT22	P-CUT25	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
<u>Trichoptera</u>												
micsma	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0
glsang	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0
goerd	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0
hyhpca	0.0	16.7	0.0	83.3	0.0	0.0	0.0	0.0	3.2	0.0	2.8	0.0
hypara	2.8	0.0	0.0	0.0	0.0	0.0	11.1	11.1	0.0	4.2	2.8	12.5
leplep	0.0	0.0	13.9	0.0	0.0	13.3	11.1	9.6	9.6	4.2	5.6	58.3
lmchry	0.0	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
limchy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
limphi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
limpsy	0.0	50.0	10.4	27.8	0.0	0.0	0.0	9.6	9.6	0.0	2.8	0.0
limnsp	27.8	0.0	41.7	55.6	20.8	37.5	3.3	0.0	19.2	0.0	0.0	0.0
odneop	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
phldol	0.0	0.0	0.0	0.0	8.3	8.3	0.0	0.0	0.0	4.2	0.0	0.0
phlwor	8.3	300.0	250.0	55.6	20.8	4.2	56.7	83.3	16.0	8.3	5.6	45.8
rhycha	5.6	0.0	10.4	41.7	62.5	29.2	13.3	11.1	3.2	25.0	16.7	16.7
uenplx	0.0	0.0	0.0	0.0	0.0	0.0	23.3	0.0	0.0	141.7	0.0	0.0
<u>Coleoptera</u>												
dryopi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
dytisc	0.0	0.0	0.0	0.0	8.3	8.3	0.0	0.0	3.2	0.0	0.0	0.0
elmhet	63.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
elmira	2.8	41.7	62.5	0.0	166.7	0.0	0.0	0.0	12.8	12.5	5.6	25.0
elmzai	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	6.4	0.0	0.0	41.7
elmid	8.3	0.0	0.0	0.0	0.0	16.7	16.7	38.9	6.4	29.2	0.0	95.8
acneus	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	12.8	0.0	2.8	29.2
ptilod	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<u>Diptera</u>												
cercer	2.8	300.0	177.1	166.7	291.7	16.7	16.7	5.6	3.2	4.2	5.6	16.7
cerfor	0.0	0.0	0.0	55.6	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
<u>Chironomidae</u>												
chpart	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0
chpoly	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Taxa listed on page 106.

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa	Taxa Code	I-CUT12	I-CUT36	I-CUT37	P-CUT10	P-CUT15	P-CUT16	P-CUT17	P-CUT21
Diptera									
Chironomidae									
Diamesinae									
	<i>Pagastia</i> sp.	0.0	0.0	0.0	0.0	13.9	0.0	0.0	104.2
	<i>Pseudodiamesa</i> sp.	0.0	8.3	0.0	12.5	0.0	16.7	27.8	0.0
Orthocladinae	<i>Brillia</i> sp.	72.9	233.3	27.8	8.3	97.2	308.3	27.8	4.2
	<i>Chaetocladius</i> sp.	20.8	75.0	55.6	25.0	27.8	16.7	33.3	0.0
	<i>Corynoneura</i> sp.	31.3	33.3	69.4	0.0	83.3	8.3	5.6	0.0
	<i>Cricotopus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Eukiefferiella</i> sp.	52.1	16.7	0.0	12.5	41.7	41.7	5.6	4.2
	<i>Heleniella</i> sp.	31.3	0.0	0.0	0.0	0.0	0.0	0.0	4.2
	<i>Heterotanytarsus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Heterotrissocladius marcidus</i> gr.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Hydrobaenus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	5.6	0.0
	<i>Krenosmittia</i> sp.	0.0	16.7	0.0	0.0	27.8	0.0	33.3	4.2
	<i>Limnophyes</i> sp.	0.0	33.3	13.9	4.2	0.0	33.3	16.7	0.0
	<i>Metricnemus</i> sp.	0.0	0.0	0.0	4.2	0.0	16.7	0.0	0.0
	<i>Orthocladus</i> sp.	0.0	0.0	69.4	0.0	0.0	50.0	0.0	8.3
	<i>Parachaetocladius</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Paracricotopus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Parakiefferiella</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.2
	<i>Parametricnemus</i> sp.	10.4	16.7	13.9	16.7	41.7	100.0	33.3	4.2
	<i>Paraphaenocladus</i> sp.	0.0	0.0	27.8	0.0	13.9	100.0	5.6	0.0
	<i>Parorthocladus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0
	<i>Pseudorthocladus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Psilometricnemus</i> sp.	10.4	0.0	27.8	4.2	27.8	16.7	55.6	0.0
	<i>Rheocricotopus</i> sp.	62.5	441.7	111.1	16.7	55.6	33.3	94.4	4.2
	<i>Smittia</i> sp.	0.0	0.0	27.8	0.0	0.0	0.0	0.0	0.0
	<i>Stilocladus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Synorthocladus</i> sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
	<i>Thienemanniella</i> sp.	0.0	0.0	0.0	0.0	13.9	0.0	0.0	4.2
	<i>Tvetenia bavarica</i> gr.	31.3	83.3	0.0	29.2	83.3	175.0	16.7	0.0
Podonominae	<i>Boreochlus</i> sp.	0.0	25.0	0.0	0.0	13.9	0.0	11.1	0.0

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa Code*	P-CUT22	P-CUT25	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
Diptera												
Chironomidae												
diapag	277.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
diapsd	0.0	0.0	0.0	20.8	0.0	3.3	0.0	0.0	4.2	8.3	4.2	0.0
orbil	13.9	66.7	10.4	152.8	41.7	16.7	56.7	50.0	6.4	45.8	36.1	70.8
orcha	0.0	0.0	0.0	41.7	0.0	3.3	3.3	0.0	0.0	0.0	0.0	4.2
orcory	0.0	33.3	0.0	97.2	41.7	6.7	6.7	0.0	3.2	0.0	0.0	4.2
orcric	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
oreuki	33.3	25.0	0.0	0.0	0.0	6.7	16.7	16.7	0.0	4.2	2.8	0.0
orhele	0.0	0.0	0.0	0.0	0.0	3.3	5.6	5.6	12.8	0.0	0.0	4.2
orhtny	0.0	0.0	0.0	0.0	0.0	66.7	0.0	0.0	0.0	0.0	19.4	4.2
orhtri	0.0	0.0	0.0	0.0	0.0	0.0	11.1	11.1	0.0	0.0	0.0	0.0
orhydr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
orkren	0.0	0.0	10.4	13.9	20.8	0.0	5.6	5.6	0.0	0.0	0.0	0.0
orklmm	0.0	8.3	0.0	55.6	0.0	0.0	0.0	0.0	0.0	4.2	2.8	4.2
ormetr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0
orthsp	5.6	33.3	0.0	0.0	0.0	3.3	0.0	0.0	0.0	4.2	19.4	0.0
orprch	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
orprcr	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
orprki	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3
orprmt	0.0	41.7	208.3	41.7	208.3	25.0	30.0	16.7	3.2	0.0	13.9	20.8
orprph	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	5.6	4.2
orport	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0
orpsue	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
orpsil	0.0	8.3	41.7	263.9	83.3	0.0	3.3	0.0	6.4	0.0	0.0	12.5
ortheo	0.0	33.3	260.4	319.4	166.7	4.2	3.3	5.6	0.0	0.0	2.8	0.0
orsmit	0.0	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0
orstil	0.0	0.0	10.4	0.0	83.3	0.0	3.3	5.6	0.0	0.0	0.0	8.3
orsyno	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
orthie	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	12.5	0.0	0.0
ortvet	11.1	83.3	72.9	416.7	41.7	0.0	13.3	27.8	3.2	12.5	0.0	33.3
podbor	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Taxa listed on page 108.

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa Code*	P-CUT22	P-CUT25	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
<u>Diptera</u>												
proodo	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
prodia	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tpbrun	0.0	0.0	20.8	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0
tpkren	0.0	0.0	0.0	0.0	8.3	0.0	0.0	0.0	3.2	0.0	0.0	4.2
tplars	0.0	8.3	62.5	41.7	312.5	0.0	20.0	44.4	99.4	0.0	97.2	0.0
tpmicro	0.0	150.0	0.0	13.9	41.7	4.2	3.3	0.0	3.2	0.0	2.8	0.0
tpmini	0.0	125.0	31.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tpnatr	0.0	25.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0
tppsec	0.0	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tpreom	2.8	0.0	10.4	13.9	20.8	12.5	0.0	0.0	3.2	4.2	5.6	4.2
tpthei	2.8	0.0	0.0	13.9	0.0	0.0	3.3	11.1	0.0	4.2	0.0	0.0
tyclad	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tycons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	191.7	47.2	0.0
tymcro	11.1	25.0	41.7	41.7	41.7	4.2	6.7	27.8	12.8	75.0	25.0	16.7
tyrhtn	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	2.8	0.0
tystem	11.1	16.7	125.0	41.7	1000.0	0.0	280.0	138.9	118.6	154.2	5.6	145.8
tyfnyt	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.4	0.0	0.0	20.8
dixdix	2.8	0.0	20.8	41.7	83.3	4.2	10.0	11.1	19.2	4.2	2.8	0.0
dixdxi	0.0	25.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
dixmer	0.0	8.3	10.4	55.6	20.8	0.0	3.3	5.6	16.0	0.0	2.8	4.2
empchf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5
emporo	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	8.3	11.1	4.2
empore	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
empsp	0.0	0.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0
glutop	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
psydip	0.0	8.3	0.0	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
simuli	2.8	50.0	0.0	0.0	0.0	4.2	13.3	5.6	0.0	75.0	11.1	4.2
thaua	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.7	0.0	0.0

*Taxa listed on page 110.

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa	Taxa Code	I-CUT12	I-CUT36	I-CUT37	P-CUT10	P-CUT15	P-CUT16	P-CUT17	P-CUT21
<u>Diptera</u>									
Tipulidae									
	<i>Antocha</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Dicranota</i>	83.3	50.0	13.9	4.2	69.4	41.7	38.9	29.2
	<i>Holorusia</i>	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>Limnophila</i>	0.0	16.7	0.0	4.2	13.9	0.0	0.0	4.2
	<i>Tipula</i>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	<i>sp.</i>	0.0	0.0	0.0	4.2	0.0	75.0	0.0	4.2
<u>Non-insectis</u>									
Acarina									
	acarin	208.3	66.7	236.1	87.5	402.8	216.7	66.7	50.0
Asellidae									
	aselid	41.7	25.0	0.0	0.0	0.0	8.3	22.2	0.0
Copepoda									
	cpoda	125.0	58.3	875.0	125.0	1097.2	91.7	77.8	58.3
Gastropoda									
	hydrob	2760.4	0.0	0.0	141.7	527.8	133.3	566.7	120.8
	<i>Juga</i>	0.0	8.3	0.0	0.0	0.0	75.0	33.3	0.0
	Planorbidae	0.0	0.0	0.0	0.0	13.9	0.0	5.6	0.0
Nematoda									
	nemtd	260.4	108.3	347.2	20.8	430.6	175.0	144.4	16.7
Oligochaeta									
	oligoc	364.6	158.3	180.6	16.7	333.3	158.3	138.9	45.8
Ostracoda									
	ostrac	218.8	83.3	111.1	29.2	111.1	0.0	11.1	8.3
Pisidiidae									
	psidi	322.9	316.7	625.0	58.3	55.6	33.3	422.2	0.0

Table B2 (Continued). Benthic densities of aquatic macroinvertebrates (individuals/m²) from the 20 headwater study sites.

Taxa Code*	P-CUT22	P-CUT25	I-FOR26	I-FOR28	I-FOR38	I-FOR40	P-FOR32	P-FOR33	P-FOR34	P-FOR35	P-FOR41	P-FOR42
<u>Diptera</u>												
tipant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0
tipdic	5.6	50.0	31.3	111.1	145.8	0.0	6.7	27.8	3.2	16.7	0.0	20.8
tiphol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tiplim	13.9	0.0	0.0	0.0	62.5	4.2	0.0	5.6	0.0	0.0	0.0	4.2
tiptip	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
tipuli	0.0	0.0	0.0	27.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<u>Non-insects</u>												
acarin	13.9	58.3	177.1	27.8	166.7	62.5	50.0	5.6	41.7	33.3	63.9	20.8
aselid	0.0	91.7	0.0	0.0	20.8	4.2	0.0	0.0	6.4	0.0	0.0	0.0
cpoda	0.0	183.3	437.5	111.1	1645.8	41.7	10.0	5.6	0.0	4.2	25.0	8.3
hydrob	8.3	0.0	41.7	944.4	1270.8	0.0	76.7	216.7	128.2	320.8	77.8	16.7
juga	0.0	8.3	0.0	0.0	0.0	0.0	56.7	105.6	3.2	0.0	0.0	37.5
planbd	0.0	0.0	0.0	0.0	0.0	70.8	0.0	0.0	0.0	0.0	0.0	0.0
nermtd	0.0	950.0	93.8	347.2	1479.2	33.3	6.7	0.0	3.2	4.2	33.3	4.2
oligoc	8.3	608.3	145.8	500.0	416.7	91.7	10.0	27.8	28.8	25.0	47.2	12.5
ostrac	11.1	8.3	0.0	250.0	395.8	8.3	0.0	0.0	0.0	8.3	5.6	0.0
psidi	5.6	175.0	229.2	152.8	41.7	20.8	10.0	5.6	19.2	50.0	13.9	25.0

*Taxa listed on page 112.

APPENDIX C: HOW TO BUILD AN EMERGENCE TRAP

There are many different types of emergence traps that vary in basal size, height, netting, and use. Ryan Taylor and Janel Banks designed these traps to be easily portable and to fit within small stream channels. The frames are hinged so they can be folded for easy carrying over rough terrain and a quick set up in streams. The 24-inch cross pieces of the trap form a shelf that 25.4 oz rectangular containers with a lip can hang off to serve as collection wells. About an inch of a 50 antifreeze:50 water mixture in each well is sufficient to capture and preserve emerging insects.

Table C1. Material for one emergence trap with basal dimensions 2' x 1' and height 1½'.

Quantity	Material
2	1" x 2" x 8' wood strips (a.k.a. furring strips)
16	finishing nails (1 ¼")
4	panel nails (1 5/8")
-	Wood Glue
2	utility hinges (1 ½")
3	rectangular plastic containers (25.4 oz) for wells
~1 yard	No-see-um netting (very fine mesh)

HOW TO BUILD THE TRAP FRAME

1. Cut each wood strip into two 24-inch pieces, two 18-inch pieces, and one 9- inch piece. All measurements and cuts are based on a circular saw blade width of 1/8". With both wood strips cut, you have a total of four 24-inch, four 18-inch, and two 9-inch sections (Figure C1).

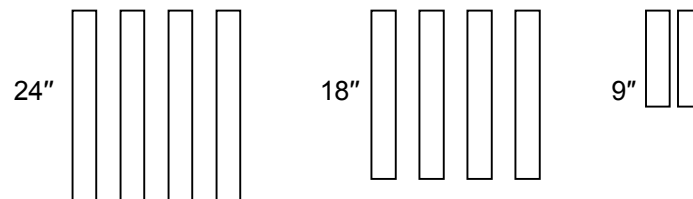


Figure C1. Number and lengths of wood strips needed for each emergence trap.

2. For both 9-inch pieces: one inch from one end cut a ¾-inch-length notch; at the opposite end, measure ½-inch from the end and mark the center (Figure C2).

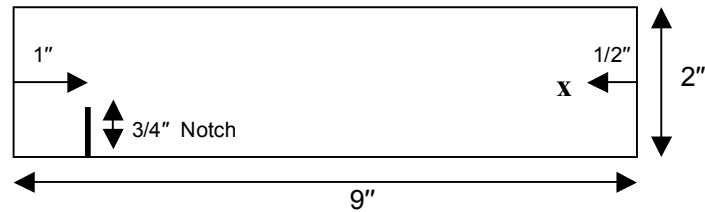


Figure C2. Notch and mark each of the two 9-inch pieces as depicted.

- To build one half of the two-part frame: mark two of the 18-inch pieces $7\frac{1}{4}$ inch down from the top. Dot some wood glue on the 2-inch wide side of the 18-inch pieces at the top of the piece and also below the mark you just made. Attach two 24-inch pieces crosswise to the 18-inch pieces by driving two $1\frac{1}{4}$ " finishing nails diagonally from each other (Figure C3). Avoid the edges because you will split the wood. Wipe off excess wood glue. Repeat this process to make both halves of the trap frame.

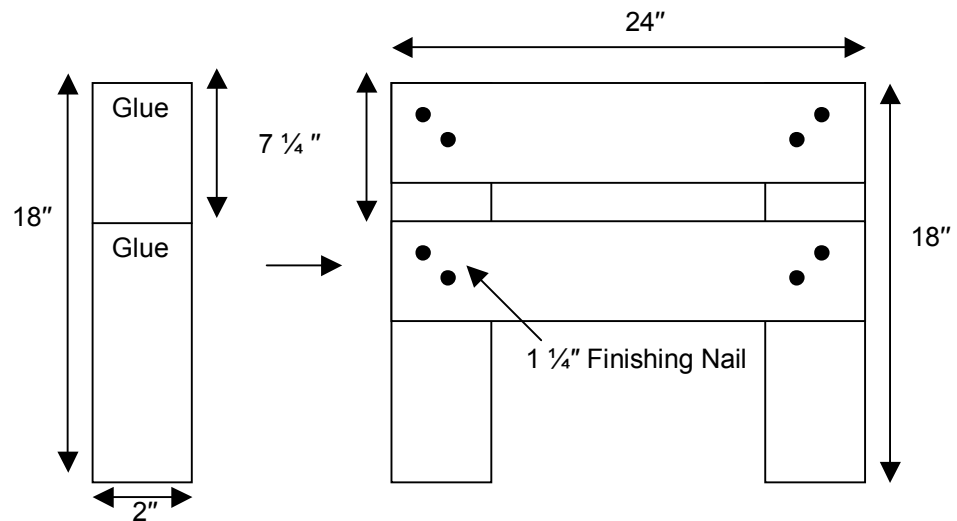


Figure C3. Two 18-inch and two 24-inch pieces make up one-half of each trap's frame.

- Orient the two halves of the frames with the 24-inch crosspieces against each other. At each end, attach the two pieces together with the $1\frac{1}{2}$ " utility hinges (Figure C4). Use the Philips head wood screws that are provided in the package of hinges.

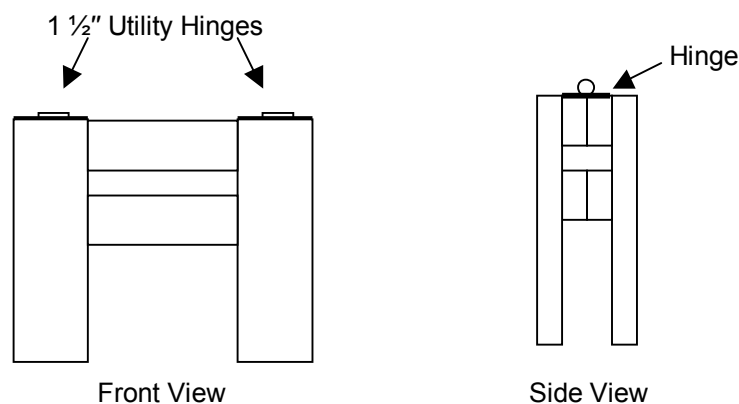


Figure C4. Front and side views of the halves of the trap frame attached by two hinges.

You then need to attach the two 9-inch pieces you prepared in step 2 in the manner described in step 5. These pieces allow the folded frame to be locked into a rigid position when deployed for sampling.

5. Set the frame upright so the 24-inch crosspieces rise vertically from the workbench. Open the frame, orienting the legs of the frame towards you and space the outside edges of the legs 12 inches apart (Figure C5A). You will be attaching each 9-inch piece so that it is hinged on a nail on one 18-inch leg and the notched end will fit over a locking nail on the opposite 18-inch leg. On the inside of the 18-inch legs of the trap, position one of the 9-inch pieces below the lower 24-inch crosspiece with the notched end oriented towards you. Adjust the position to make sure that the notch in the 9-inch piece lines up with the center of the opposite 18-inch leg, and that the locking-nail will be far enough below the 24-inch crosspiece to allow the notch to clear the nail when you fold-up the trap. Once the appropriate position has been achieved, attach the marked end of the 9-inch piece with a 1 5/8" panel nail that has been driven through a plastic scrap from the lids of the containers to be used as wells (Figure C5B). The plastic acts as a washer to keep the nail from working through the wood. On the opposite 18-inch leg, drive a panel nail through the notch and partially into the 18-inch leg to

serve as a catch for the notch (the “locking-nail”). Rotate the trap and repeat for the opposite side making sure that the notched ends of the 9-inch pieces are on the same side of the trap

Note: There are no precise measurements for the placement of the 9-inch pieces because the furring strips generally contain imperfections. The position of the 9-inch pieces must be modified for each trap so that the base opens to 12-inches when the trap is locked into position.

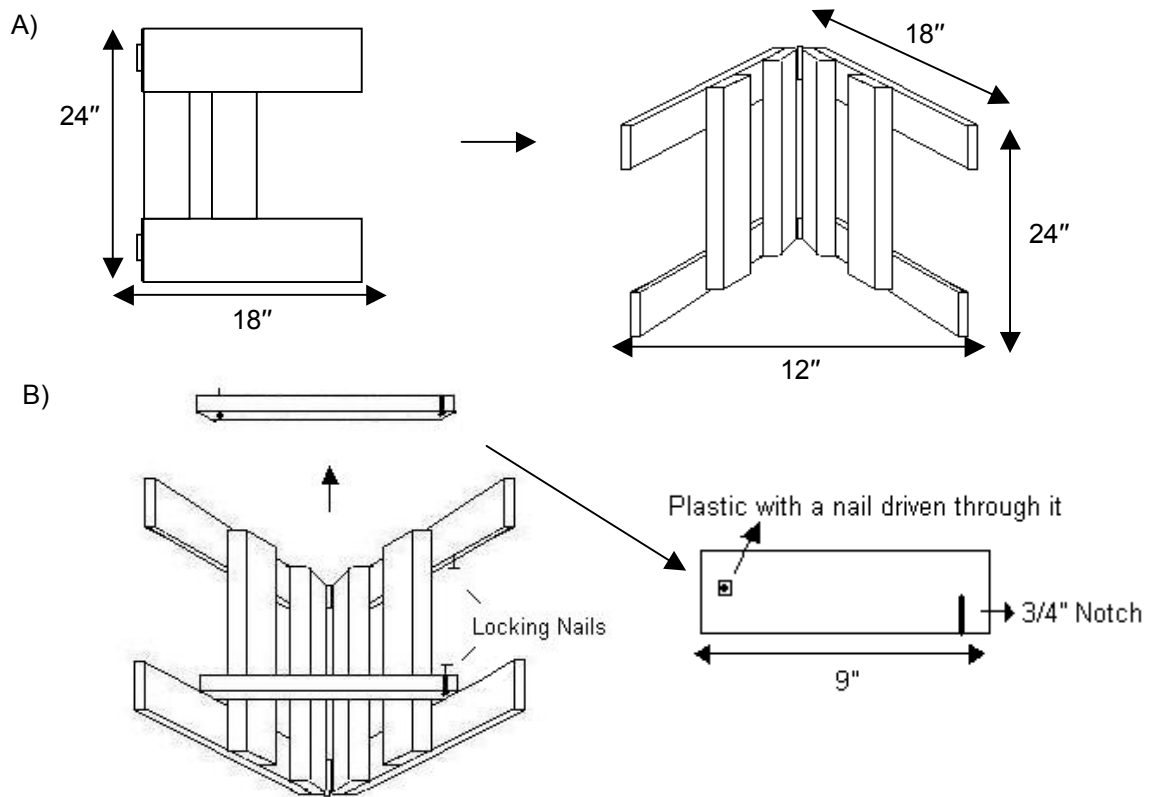


Figure C5. Position the trap so the legs are 12 inches apart (A). Then attach each 9-inch piece so that one end is hinged with a nail and the opposite end with the notch is able to fit over a locking-nail (B).

HOW TO SEW THE NET

Roughly one yard of no-see-um is needed to make a cover that fits over the wooden frame. It is best to make a pattern from paper to use as a template for the pieces. Cut one big rectangle that fits over the 2' sides of the trap when draped over the frame. Cut two-trapezoidal pieces to fit each end (Figure C6A). All three pieces are sewn together with nylon thread. First sew the top of

each trapezoidal piece to the edges at the center of the rectangular piece (Figure C6B). Then fold the rectangular piece in half and hem the long edges of each of the trapezoidal pieces to the edges of the rectangular piece, but stop these hems approximately two-inches from the end so there is a flap on each side to anchor the net in the field (Figure C6C).

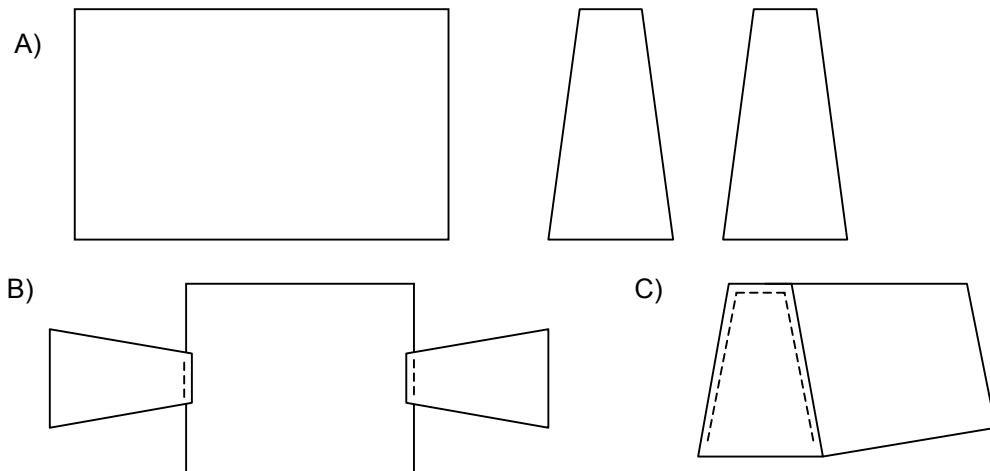


Figure C6. Pieces of no-see-um netting needed for the emergence trap net (A). Attach the top of each trapezoidal piece at the edges of the center of the rectangular piece (B). Then attach the long-edges of the trapezoidal pieces to the rectangular piece, stopping the hem about two-inches from the end (C).

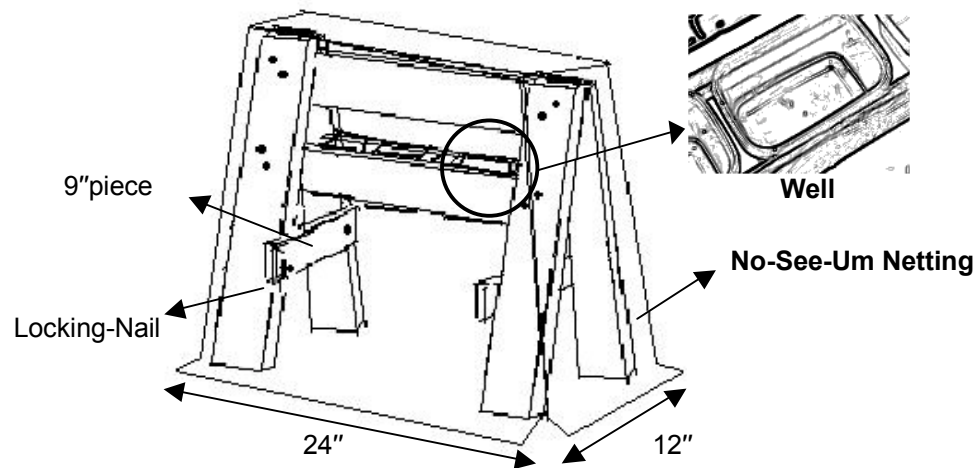


Figure C7. To set up the emergence trap, first open the frame and lock the 9-inch pieces in place by fitting the notch over the locking-nail. Place 3 wells in the frame with the lips of the containers supported by the 24-inch cross pieces. Put 1 to 1 ½ -inches of liquid (50 antifreeze: 50 water) in each well. Cover the trap with the net and anchor the bottom with in-situ material.