

COMPOSITION, ABUNDANCE AND BIOMASS
OF MACROINVERTEBRATE DRIFT
IN A SOUTHERN APPALACHIAN CREEK

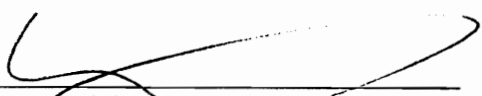
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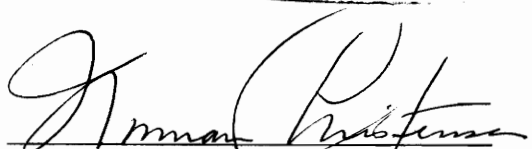
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Abstract

The downstream transport of invertebrates in the water column, drift, is an important process in stream ecology. For example, drift is a major food resource for a variety of stream fauna including predatory invertebrates, and fish such as trout.

In the Wine Spring Creek watershed in the Nantahala National Forest of Southwestern North Carolina, forest service managers have established an ecosystem management goal of either maintaining or increasing the productivity of invertebrates and trout. To monitor the success of this goal, baseline information on the drift community was needed. In response to this need, this study characterized the composition, abundance and biomass of drifting invertebrates in the creek.

During the summer of 1996, whole-stream drift was sampled both day and night from the creek and an unnamed tributary using specially designed 'drift traps'. A total of 19,152 invertebrates were collected: 15,967 aquatic and 3185 terrestrial. Abundance and biomass of the aquatic fraction of drift was significantly greater at night; no diel difference was found in the terrestrial fraction. During the day, the mean biomass (ash-free dry mass) of terrestrial taxa (0.09 mg/m^3) was approximately equivalent to the biomass of aquatic taxa. Analysis of spatial patterns of drift revealed that terrestrial drift density was correlated with mean wetted channel width according to the following non-linear model: $\text{terrestrial density} = 2.87 * \text{Exp}(-0.53 * \text{mean width})$. This model yielded an $r^2 = 0.26$ and an F-statistic = 0.00071.

These findings suggest that (1) there is little excess food available in the drift to sustain additional invertebrate or trout productivity, and (2) terrestrial invertebrates are an important component of the daytime drift and therefore management of the fishery should emphasize the strong link between the creek and the riparian zone.

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1. Introduction

1.1. Drift: An Overview

Invertebrate drift is commonly defined as the downstream transport of invertebrates in the water column (Allan, 1995). In fast-flowing, temperate streams, the most abundant drifting invertebrates are often aquatic insects (Scullion and Scinton, 1983). Other aquatic invertebrates, such as amphipods, are also commonly found (Iversen and Jessen, 1977). Terrestrial invertebrates can also be abundant in drift, especially during the summer (Edwards and Huryn, 1995).

Drift density, or the number of drifting organisms per unit discharge, is often used to describe quantitatively the abundance of drifting organisms (Allen and Russek, 1985). The highest drift densities have been recorded below lake outflows, with values exceeding 20,000m³. Usually drift densities are several orders of magnitude lower than this figure, especially when microscopic drifting organisms are excluded from density estimates (Brittain and Eikland, 1988). Because drifting organisms are often small, quantifying drift strictly in terms of density can be misleading. For example, two samples of drift could have a similar density yet drastically different biomass. Therefore, another way drift is commonly quantified is biomass per unit discharge (e.g. Edwards and Huryn, 1995; Ohop and Wallace, 1983).

Drift has been correlated with many abiotic factors. However, correlation does not always mean causation; many factors probably affect drift indirectly (Brittain and Eikland, 1988). Some of the most common abiotic factors include water temperature, current and discharge, substrate type, vegetational cover, light intensity, depth, and the presence of pools (Brittain and Eikland, 1988; Elliot, 1971). Of these factors, discharge is one of the most influential. Several studies have found

that drift significantly increases during spates and floods. During these periods, scouring of the substrate has been suggested as the cause of increased drift (Crisp and Robson, 1979; Byrd and Hynes, 1981). At the other extreme, periods of low discharge have also been linked with drift (Minshall and Winger, 1968).

Many studies have found significant relationships between drift and temporal factors such as season and time of day: This may be because temperature and photo period are strongly correlated with drift. For example, in temperate climates drift density is normally lowest in winter and highest in summer (Clifford, 1972; Stoneburner and Smock, 1978). Perhaps the most frequently documented temporal aspect of drift is its consistent diel (day vs. night) periodicity. Drift densities are almost always greatest at night, usually shortly after sundown (Allen and Russek, 1985; Brittain and Eikland, 1988).

In contrast with temporal differences, drift densities appear to be relatively uniform spatially--at least at the watershed scale. For example, in a study of a Southern Appalachian stream, Turner (1994) found little evidence of changes in drift density along a gradient in elevation and stream size. While drift densities may be relatively uniform along the stream continuum, the distances of drift can vary considerably: from several centimeters to several kilometers, depending upon the type of invertebrate and hydrologic factors such as current velocity and discharge (Elliot, 1971; Brittain and Eikland, 1988). For example, Waters (1965) completely blocked drift in a stream and found that neither *Baetis* nor *Gammarus* reached normal drift rates at a distance of 38m below the block. For these taxa Waters concluded that daily drift distances were greater than 38m.

Certain biotic factors have also been correlated with drift. For example, drift is often dominated by early instars, and may be a behavioral means of dispersal for small taxa avoiding

competition or predation by larger invertebrates and fish (Walton, 1980). Compared with small drifting organisms, large organisms may have less of a propensity to drift because they suffer a greater risk of predation by sight feeding predators such as trout. The significant increase in drift densities at night seems to lend support to this theory (Flecker, 1992).

There are many abiotic and biotic factors that cause organisms to drift. However, the causes of drift do not necessarily have to be understood to explore the ecological consequences of drift. One of the most significant consequences of drift is its importance as a food resource for aquatic insects such as net-spinning caddisflies (Benke and Wallace, 1980) and for fish such as trout (Allen, 1981; Tippetts, 1978; Elliot, 1967).

1.2. Purpose and Objectives

The US Forest Service has selected the Wine Spring Watershed in the Nantahala National Forest of North Carolina to demonstrate its new ecosystem management approach to forest stewardship. In accordance with this ecosystem approach to management, the Forest Service has identified a series of goals for the watershed. Two ecosystem management goals specific to Wine Spring creek and its tributaries are as follows: (1) populations of native fish species in Wine Spring Creek and tributaries which equal or exceed current levels, and (2) increased productivity in selected stream reaches in terms of measured dissolved calcium concentration and/or biomass of algae, invertebrates, and fish (Swank, file report). To support these goals, this project was undertaken because information existed for benthic invertebrates (e.g. Wohl et al, 1995; Hutchins unpublished data) and fish (e.g. Flebbe, unpublished data), but information on the drift community did not (J. B. Wallace, personal communication).

To describe the drift community in Wine Spring Creek and its tributaries, as well as its potential importance as a food resource for fish, the following four objectives were identified for this study: (1) to describe the taxonomic composition, abundance, and biomass of drifting aquatic and terrestrial macroinvertebrates, (2) to describe the diel periodicity of drift in terms of macroinvertebrate abundance and biomass, (3) to investigate correlations between the abundance and biomass of drift and selected physical parameters of the stream, and (4) to determine the spatial abundance of drifting terrestrial and aquatic invertebrates.

1.3. Study Area

The Wine Spring watershed is located in the Wayah Ranger District of the Nantahala National Forest, in the Southern Appalachians of southwestern North Carolina (Figure 1a). This 4,432 acre mountainous area is drained by many low-order, high-gradient streams, which are often heavily shaded by a canopy of deciduous hardwoods and a dense under story of rhododendron (*Rhododendron* spp.). The study area was located in the upper portion of the watershed (Figure 1b). Drift samples were collected from three sampling sites within each of three separate reaches (Figure 1b): two of the three reaches (UWC and LWC) were located on the main part of Wine Spring Creek; the third reach (TRIB) was located on an unnamed tributary of Wine Spring creek. The general physical features of the three reaches are presented in Table 1a; the physical dimensions for each of the 9 sampling sites are presented in Table 1b.

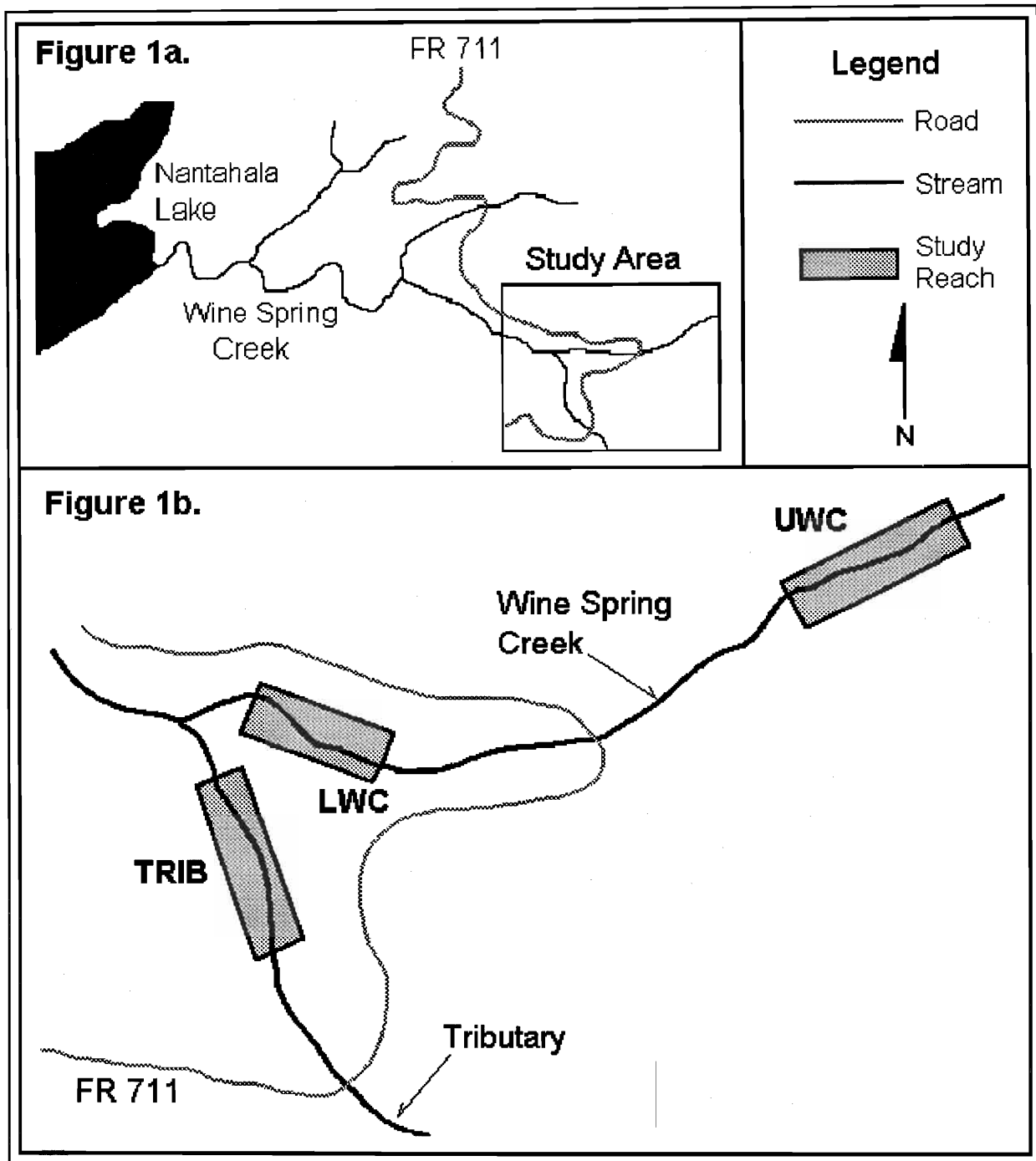


Figure 1a. Map of the Wine Spring Watershed, located in the Wayah Ranger District, Nantahala National Forest in Southwestern North Carolina. **Figure 1b.** Map of the three reaches sampled for this study. Figures not to scale.

Table 1a. Characteristics of the study reaches in the Upper Wine Spring watershed.

	LWC	UWC	TRIB
Stream Order ¹	3	3	2
Elevation ² (m)	3970	4120	3960
Distance From Source ² (m)	2590	1980	730
Mean Width ³ (m)	4.1	3.5	2.4
Canopy	moderate shade	moderate shade	dense shade
Discharge ⁴ (L/s)	47	37	22

1. Based on personal observation using the Horton (1945) classification system.
2. Calculated from USGS 1:24000 map (Wayah Bald, NC).
3. Wetted channel width measured at nine randomly selected locations in each reach.
4. Depth*width*velocity (calculated using Pygmy brand flow meter: see methods).

Table 1b. Characteristics of each study site in the Upper Wine Spring watershed.

Site	Discharge (L/s) ¹	Length (m) ²	Mean Width (m) ³
LWC1	43	Control	4.0
LWC2	49	20	4.2
LWC3	49	25	4.0
UWC1	24	Control	2.6
UWC2	50	30	3.6
UWC3	37	11	4.3
TRIB1	24	Control	2.5
TRIB2	22	20	2.1
TRIB3	20	14	2.6

1. Depth*width*velocity (calculated using Pygmy brand flow meter: see methods).
2. Distance between drift traps.
3. Wetted channel width measured at three randomly selected locations in each site.

2. Materials and Methods

2.1 Sample Design

Many studies of drift use a single net for sampling. In large streams, the net catches only a fraction of the total discharge and therefore only a fraction of the total drift. To estimate total drift using a single net, the discharge filtered by the drift net and the total discharge of the stream are measured. Drift in the entire stream is then calculated by multiplying the amount of drift captured in the net by a correction factor (total discharge divided by discharge through the net). This method implicitly assumes that the organisms captured in the net are representative of the drift community in the entire cross-section of the stream. Several studies have tested this simplifying assumption and found that it is not necessarily valid, even for small streams where one might expect that drift would be fairly uniform spatially (Brittain and Eikland, 1988). To overcome this simplifying assumption, specially designed 'drift traps' were constructed for this study (Figure 2). These traps were built by modifying wedge dams¹ with rocks, plywood and 2x2's. Wedge dams were ideal locations for drift trap construction, since they significantly constricted the width of the creek.

To ensure that whole-stream drift was sampled only from known areas in the creek and its tributary, the following criteria were used for choosing sampling sites: (1) the presence of wedge dams which could be modified into drift traps, and (2) wedge dams in series of three. All three wedge dams were modified into drift traps: the drift trap furthest upstream served as a control, while the two sequential downstream traps only sampled drift from a known area in the stream. All three reaches

¹Wedge dams are v-shaped instream structures composed of large logs and rocks. They were built by the US Forest Service in Wine Spring Creek and its unnamed tributary to create pools and off-channel habitat for trout (USFS unpublished information).

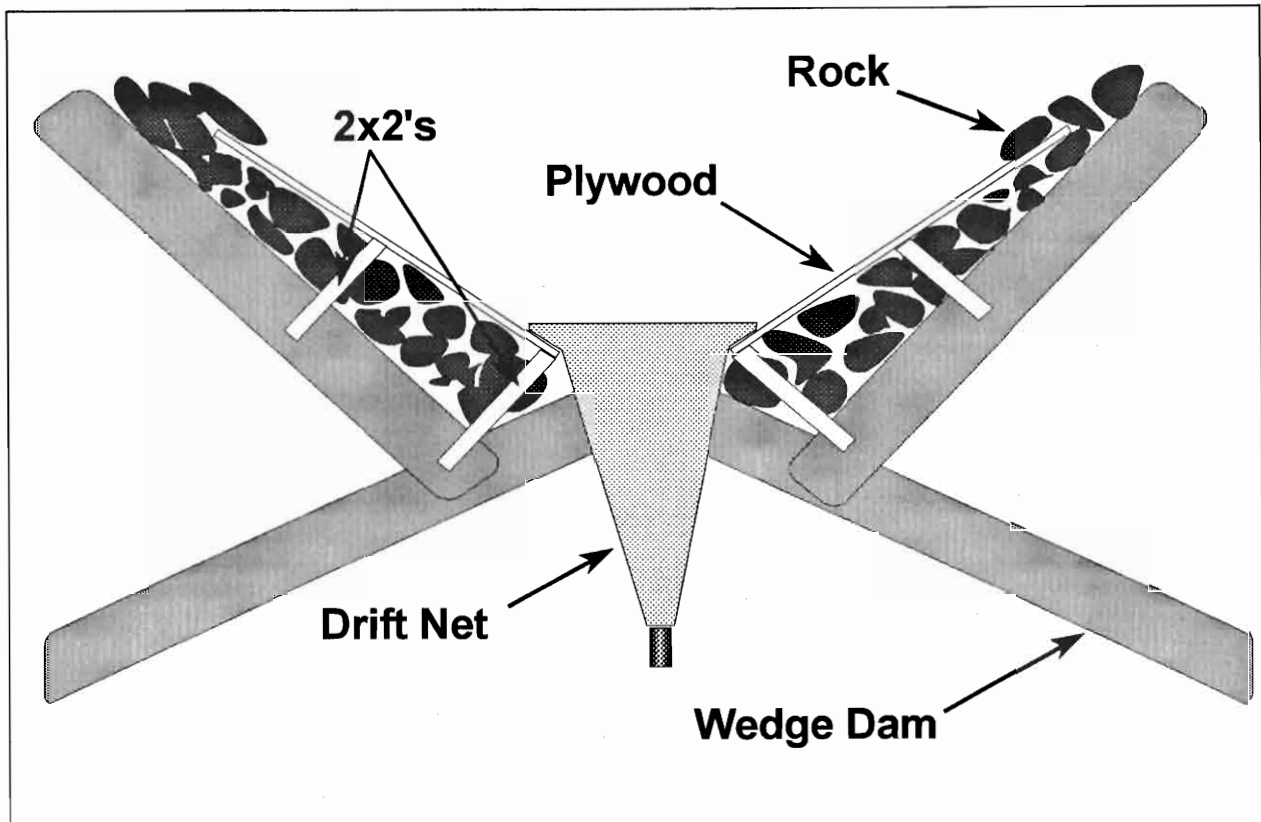


Figure 2. Top view of a typical drift trap. These traps were designed to capture all organisms drifting in the creek.

chosen for sampling met the first criterion; UWC, however, had only one wedge dam and therefore did not meet the second criterion. Nonetheless, it was chosen for sampling because no other locations were found suitable for drift trap construction. In UWC, A downed log and a deflector² constricted the stream channel sufficiently enough to allow for drift trap construction.

2.2 Drift Traps

Nine drift traps were constructed: three traps in each of the three reaches (Figure 2). The

²Deflectors are essentially half a wedge dam, designed to prevent bank erosion and create off-channel pools as habitat for trout (USFS, unpublished information).

traps were designed to direct all of the stream flow through a 0.46m opening in the middle of the trap. By slipping a drift net (250 μ m mesh size) into the trap, all drifting organisms in the stream larger than 250 μ m would theoretically be captured. In practice, however, some water flowed around gaps in the rock and plywood. Drift nets also clogged over time, and clogging reduced their ability to filter all of the discharge and therefore capture 100% of the drift. To reduce net clogging, drift sampling was limited to one hour. This interval was chosen because it appeared to be the maximum length of time for sampling before net clogging caused water to back up and bypass the drift trap.

2.3 Drift Sampling

Drift samples were collected from each of the nine sampling sites on the following dates during the summer of 1996: (1) June 29-30, (2) July 12-13 and (3) July 27-28. Each sampling session required two days because there were nine sampling sites, but only six drift nets were available. To account for the potential diel periodicity of drift, drift samples were collected for approximately one hour at mid-day and shortly after sunset (usually beginning @ 10 PM). Nets were inserted into the mouth of each drift trap and held firmly in place by force of the current. To ensure that all drifting organisms originated within each sampling site, the net furthest upstream (the control) was placed first, followed by the second and third downstream nets. A two minute time interval between net placement was necessary to ensure that all drifting invertebrates of unknown origin were flushed from each downstream site. Also to guard against capturing drifting organisms of unknown origin, nets were removed in the reverse order that they were placed.

2.4. Physical Measurements

Prior to each one hour sampling period, water velocity was measured at each net opening using a Pygmy brand velocity meter. Each net opening was divided into thirds, and velocity was measured using the sixth-tenths-depth method at the midpoint of each third. At each point where velocity was measured, the depth of flow was also measured. Depth was then multiplied by velocity and width to calculate discharge for each third of the net opening. Mean discharge through each net was then calculated by averaging the discharge for each third. Flow velocity and depth were only measured prior to sampling, since it was assumed that discharge was constant over the one hour sampling period. This assumption was used because samples were never collected during transient periods (e.g. storms).

The substrate composition at each of the nine sampling sites was measured using a 'pebble count' method. This method entails walking along the stream bed in a zig-zag fashion and randomly picking up rocky material from the substrate. Care was taken to insure that the first substrate touched was measured, to reduce bias toward collecting large substrate. A minimum of 100 substrate samples were collected at each sampling site. Substrate size was measured by fitting each sample (except boulders) through a specially designed aluminum plate with 12 square holes corresponding to the following size categories:

1. Boulder: >256mm
2. Cobble: <256mm, <128mm, <90.5mm
3. Pebble: <64mm, <45.3mm, <32mm, <22.6mm
4. Gravel: <16mm, <11.3mm, <8mm, <4mm
5. Sand: <2mm

The substrate throughout the entire length of each of the six treatment (blocked) sites (sites 2 and 3 in each reach) was categorized. For the three control sites, substrate size was measured to 15m upstream of each drift trap. An additional category, Bedrock, was also added to the substrate characterization, because bedrock outcrops comprised a significant fraction of the substrate in the TRIB and UWC reaches.

The wetted channel width at each site was also measured in at least three locations to calculate mean channel width. For the control sites, mean width was randomly measured to 15m upstream of each drift trap. Channel length at each of the treatment sites was measured as the distance between the mouth of the drift traps at sites 2 and 3. A single length measurement was taken, since the channels were nearly straight at all three reaches.

2.5. Sample Processing and Macroinvertebrate Identification

Samples were preserved in the field using a 6-8% formalin solution stained with Phloxine B dye to facilitate separating invertebrates from detritus. In the lab, drift samples were sieved into greater than 1mm and less than 1mm size fractions using 1mm and 250 μ m nested sieves. A stereo dissecting scope was used to facilitate sorting and identification.

Macroinvertebrate taxa were separated into aquatic and terrestrial categories according to the following definitions: Aquatic taxa were defined as all larval aquatic insects, oligochaetes and Crustacea. Terrestrial taxa were defined as all other invertebrates including winged adult aquatic insects.

Aquatic insect larvae were identified to the genus level whenever possible according to Merritt and Cummins (1996), Brigham et al (1982), and Wiggins (1996). Pupae abundance was documented

but not used in any analysis of density or biomass. Non-insect taxa (Crustacea, Gastropoda, Arachnida, and Collembola) were identified to order or higher. The length (in mm) of all larval aquatic insect taxa and Collembola was also measured by placing each invertebrate over graph paper with 1mm grids. Terrestrial taxa were identified in 5 broad categories: (1) winged, (2) non-winged, (3) Collembola, (4) Gastropoda, (5) Arachnid.

2.6. Biomass Estimates

The biomass of larval aquatic insects was estimated using length/mass empirical relationships (J. B. Wallace, unpublished data). Terrestrial taxa were dried at 60C-70C for a minimum of 48 hours, then the dry weight for each drift sample was measured to the nearest microgram using a Sartorius brand microbalance. The ash-free dry mass was calculated as 90% of the dry biomass.

3. Results and Discussion

3.1. Composition and Abundance of Drift

A total of 54 drift samples were collected on six separate occasions (3 day, 3 night) during June and July, 1996. Due to time constraints, however, only 42 samples were analyzed. The 12 samples not analyzed were collected on the second and third sample dates from LWC2, UWC2, and TRIB2. The samples that were analyzed contained 19,152 invertebrates: 15,967 were considered aquatic, and 3,185 were designated as terrestrial. The aquatic fraction of drift was dominated by aquatic insects; only 2% of aquatic invertebrates were not larval aquatic insects. The taxonomic composition of the 65 different types of aquatic taxa collected in the drift is listed in Appendix 1.

Approximately 85% of the drifting terrestrial invertebrates were either Collembola and winged insects. The percent composition of all terrestrial invertebrates is shown in Appendix 2.

Although 65 different aquatic taxa were collected in the drift, only 15 of these comprised 95% of the abundance (Appendix 3). Of these 15, the mayfly *Baetis* sp. accounted for 48% of the abundance. The high abundance of *Baetis* in drift has been documented in numerous other studies as well (e.g. Stoneburner and Smock, 1978; Waters, 1965; Clifford, 1972). The next two most abundant taxa, *Simulium* sp. and Chironomidae, each accounted for slightly greater than 10% of the drift abundance. Other aquatic insect orders consistently represented in the drift included Plecoptera and Trichoptera.

When the percent composition of aquatic drift by biomass was analyzed, a slightly more complex picture emerged: 21 taxa comprised approximately 95% of the total biomass of the drift (Appendix 4). As with abundance, *Baetis* also ranked first in terms of biomass. Some occasional drifters, however, accounted for a significant fraction of the total biomass. The most notable was the dragonfly *Lanthus* sp. Only one *Lanthus* was collected during the entire study, yet it accounted for almost 5% of total biomass of all the drift. It was also by far the largest larval aquatic insect captured, with a length of 23 mm. In contrast, the weighted mean length of all aquatic insect taxa was only 2mm. A histogram showing the length distribution of larval aquatic insects is presented in Appendix 6.

3.2. Temporal Patterns

To determine if drift densities varied significantly over the course of this study, drift densities for all three sampling dates were compared using 2 sample t-tests at a 95% confidence interval.

Three categories of drift density were compared: (1) aquatic, (2) terrestrial, and (3) total (aquatic+terrestrial). No significant differences ($\alpha=0.05$) were detected for any of the categories (Table 2). A similar analysis was done for drift biomass, and no significant differences ($\alpha=0.05$) were apparent (Table 3). These results are perhaps best explained by the short duration of this study (roughly one month), as seasonal differences in drift densities are often reported for temperate regions (Clifford, 1972; Stoneburner and Smock, 1978; O'hop and Wallace, 1983; Turner, 1994).

The second objective of this study was to describe the diel periodicity of drift in terms of both density and biomass. Since there was no significant difference in drift density or biomass over all three sampling dates, the data for both density and biomass were pooled to calculate mean density and biomass. Density ($\#/m^3$) was calculated for each site as the number of drifting invertebrates per net hour divided by discharge per net hour. Biomass (mg/m^3) was estimated as mg (ash free dry mass) per net hour divided by discharge per net hour. While every effort was made to sample drift for one hour periods, nets had to be removed at slightly different times and therefore correcting the density and biomass estimates by sampling time (net hour) normalized these differences. Mean density and mean biomass, both day and night, were calculated for all sites combined and for each of the three reaches. Two-sample t-tests at a 95% confidence interval were used to determine if there were significant diel differences. These results are presented in Table 2 for density and Table 3 for biomass.

Both density and biomass for all sites combined and by reach were significantly greater at night ($\alpha=0.05$). These findings complement those of O'hop and Wallace (1983). They studied drift in Southern Appalachian headwater stream and found greater nighttime abundances of larger

mayflies, stoneflies, and blackflies. However, these findings do not agree with those of Turner (1994), who found no significant increases in nighttime drift abundance.

Table 2. Mean and mean standard error (SE) for day and night density ($\#/m^3$) of drifting macroinvertebrates for all sites and for each reach. Significant diel differences ($\alpha=0.05$) were calculated using 2 sample t-tests for means.

	All Sites	LWC	UWC	TRIB
Day	2.6	1.0	3.4	3.2
SE day	0.5	0.1	1.0	0.9
Night	6.2	3.7	8.3	6.2
SE night	1.0	0.6	1.9	1.9
Significance	0.0026	0.0013	0.042	0.016

Table 3. Mean and mean standard error (SE) for day and night biomass (mg/m^3) of drifting macroinvertebrates for all sites and for each reach. Significant diel differences ($\alpha=0.05$) were calculated using 2 sample t-tests for means.

	All Sites	LWC	UWC	TRIB
Day	0.18	0.10	0.19	0.24
SE day	0.03	0.02	0.05	0.08
Night	0.91	0.74	1.06	0.90
SE night	0.16	0.07	0.36	0.27
Significance	0.00017	6E-06	0.036	0.038

In addition to comparing diel differences in total drift density and biomass, the density and biomass of the terrestrial and aquatic fraction of the drift were also compared. This analysis was done to see if diel differences in density and biomass between the aquatic and terrestrial fraction of the drift conformed to the same pattern as total density and biomass. To do this calculation, the density and biomass data for all sampling locations and for each reach were pooled into two sets, day and night. Each set was then divided into aquatic and terrestrial categories. The means for these two categories were then compared for differences in density and biomass between day and night using 2 sample t-tests at a 95% confidence level. These results are presented in Table 4 for density and Table 5 for biomass. Significant diel differences ($\alpha=0.05$) in both density and biomass were found for the aquatic fraction of the drift. No significant diel differences ($\alpha=0.05$) in density or biomass were found for the terrestrial fraction. These results for biomass agree with those of Edwards and Huryn (1995), who found no significant differences in terrestrial biomass between day and night in their study of terrestrial invertebrates in New Zealand streams. In contrast with biomass, they documented significantly greater abundances of drifting terrestrial invertebrates during the day. Although not significant, in this study the abundance (density) of terrestrial drift was usually higher during the day. These findings suggest that the diel differences in total drift density and biomass were strongly influenced by the differences in the aquatic fraction of drift. They also underscore the importance of analyzing the aquatic and terrestrial fractions of the drift separately, as combining all taxa potentially masks temporal drift patterns.

Table 4. Mean and mean standard error (SE) for day and night density (#/m³) of the aquatic and terrestrial fraction of drifting macroinvertebrates for all sites and for each reach. Diel differences were calculated using 2 sample t-tests for means at a 95% confidence level ($\alpha=0.05$).

	All Sites		LWC		UWC		TRIB	
	Aquat.	Terr.	Aquat.	Terr.	Aquat.	Terr.	Aquat.	Terr.
Day	1.7	0.9	0.6	0.3	2.7	0.7	1.7	1.5
SE	0.4	0.25	0.09	0.06	0.9	0.1	0.4	0.6
Night	5.6	0.6	3.5	0.2	7.5	0.9	5.5	0.8
SE	0.9	0.1	0.6	0.03	1.8	0.2	1.8	0.2
Significance	0.0005	0.39	0.001	0.20	0.034	0.45	0.050	0.27

Table 5. Mean and mean standard error (SE) for day and night biomass (mg/m³) of the aquatic and terrestrial fraction of drifting macroinvertebrates for all sites and for each reach. Diel differences were calculated using 2 sample t-tests for means at a 95% confidence level ($\alpha=0.05$).

	All Sites		LWC		UWC		TRIB	
	Aquat.	Terr.	Aquat.	Terr.	Aquat.	Terr.	Aquat.	Terr.
Day	0.10	0.09	0.04	0.06	0.14	0.05	0.10	0.15
SE	0.07	0.03	0.01	0.02	0.04	0.02	0.04	0.04
Night	0.78	0.13	0.58	0.15	0.92	0.14	0.81	0.09
SE	0.17	0.03	0.10	0.01	0.31	0.07	0.27	0.03
Significance	3E-05	0.32	0.0003	0.38	0.028	0.20	0.022	0.34

A comparison of drift numbers and biomass between this study and that of O'hop and Wallace (1983) (who studied drift in the same geographic region) is presented in Table 6. The estimates of terrestrial abundance and biomass are in general agreement, although abundance is lower in this study. The values for the aquatic fraction of drift, however, are almost an order of magnitude higher for this study. This difference may be due to several factors. First, the stream in their study (mean width of ~1.5m and an annual mean discharge of 19.0 L/s) was smaller than the reaches sampled for this study (Table 1a and 1b). Turner (1994) studied drift along a stream continuum and documented greater abundances of drift as stream order increased. Therefore, the larger size of the streams in this study may account for the greater abundance of aquatic drift. Second, O'hop and Wallace (1983) sampled drift for an entire 24 hour period. In contrast, the estimates of daily drift abundance and biomass for this study are based on samples collected for approximately one hour during mid-day and shortly after sunset. Extrapolating these calculations to a 24 hour timeframe may inflate actual values for daily drift, since drift values for samples shortly after sunset often represent the maximum abundance of drift (Allen and Russek, 1985). Finally, O'hop and Wallace (1983) suggested that their drift values were very low; therefore, drift could simply be higher in the streams in this study.

Table 6. Regional comparison of daily drift abundance and biomass. Data from O'hop and Wallace (1983) are the means of drift for June and July combined.

	Aquatic Drift		Terrestrial Drift	
	Abundance (#/day)	Biomass (mg/day)	Abundance (#/day)	Biomass (mg/day)
This study	9000	1067	1728	294
O'hop and Wallace (1983)	1476	155	2473	110

3.3. Spatial and Physical Relationships

The third objective of this study was to determine if any relationships existed between drift density, biomass and stream spatial/physical characteristics. It was hypothesized that differences in substrate composition and stream size among sites might have affected either the abundance or composition of the drift.

The results of the substrate survey are presented in Appendix 5. The substrate composition at each of the nine sampling sites was generally similar. Cobble and pebble were the two most abundant size fractions; the boulder and sand categories were the least abundant. There was one notable exception to the general similarities in substrate composition: more than 20% of the substrate at TRIB3 was dominated by bedrock. In addition, the bedrock was located directly upstream of the drift trap.

With the exception of TRIB3, no attempt was made to correlate substrate composition with the aquatic drift, given the general similarity in substrate among sampling sites. The density and biomass of day and night drift at TRIB3 were compared with all other sites using 2 sample t-tests at a 95% confidence level. No significant differences ($\alpha=0.05$) in density or biomass were detected.

Regression analysis was used to determine if stream width correlated with drift densities. When necessary, variables were either exponentially or log transformed to normalize their distributions. In these instances, the transformation which yielded the highest r^2 was chosen. To eliminate the variance associated with diel differences in aquatic density, the aquatic and terrestrial fractions of the drift were analyzed separately.

The strongest correlation between mean stream width and terrestrial density was found using the following non-linear regression model: $\text{terrestrial density} = 2.87 * \exp(-0.53 * \text{mean width})$. This

model yielded an $r^2=0.26$ and an F-statistic=0.00071 (Appendix 7). When an influential outlier was removed from the regression calculation, the correlation between terrestrial density and stream width increased to $r^2=0.30$. The inverse relationship between terrestrial insect density and stream width suggests that fewer terrestrial insects are captured in the drift as stream width increases. Several factors may explain this relationship. At narrower widths the stream is in greater contact with the stream bank and the riparian zone, where terrestrial insects originate. In this study the narrowest reach, TRIB, was also the most densely covered with vegetation; as stream width increased, the canopy over the stream decreased (Table 1). This reduction may have led to fewer inputs of terrestrial insects, if one of the sources of terrestrial insects to the stream was from insects falling from the forest canopy.

The correlation between aquatic density and stream width was analyzed by regressing aquatic density against mean width and an intercept dummy variable representing day (0) and night (1). The dummy variable was used to correct for the significant diel differences in aquatic drift density noted previously. In contrast with terrestrial density vs. mean width, no significant relationship ($p=0.07$) was found for aquatic density vs. mean width. This finding of no significant relationship may be explained by the multitude biotic and abiotic factors that have been correlated with aquatic invertebrate drift. Perhaps a better way of analyzing the relationship (if any) between the shape of the channel and drift would have been a regression of aquatic drift vs. the mean wetted perimeter. While difficult to quantify in rocky, shallow headwater streams such as those in this study, the wetted perimeter would have accounted for the complexity of the stream bed and the full contact length between the stream water and the bank.

3.4. Drift Blocking Experiment

The method used in this study of sampling whole-stream drift provided the opportunity of determining the effect (if any) that removal of all drifting organisms had on drift densities at downstream sampling sites. This effect was important to determine for several reasons. First, if densities declined downstream (at sites 2 and 3), then estimates of the drift composition, density, and biomass for the first three objectives of this study would not truly reflect the actual conditions of the stream; the sampling method used in this study of trapping the entire drift would have interfered with sampling replicates downstream. Second, if reductions in density were found at downstream locations, this would give some indication of the distance of drift. For example, Waters (1965) performed a whole-stream drift blocking experiment and found reduced drift abundances as far as 38m past the block, in a stream section composed two riffles and an intervening pool. Because drift was reduced downstream, he suggested that daily drift was greater than 38m. Given Water's findings, and the fact the no distance between the six treatments in this study was greater than 30m, it was hypothesized that there would be significant reductions in downstream drift densities.

To test this hypothesis, data for drift density were placed in two categories: blocked and control. The control data were the estimates of drift density (three categories: aquatic, terrestrial and all taxa) collected from the nets furthest upstream in each reach. The blocked data represented estimates of drift density (three categories: aquatic, terrestrial and total) from the two sequential downstream nets in each reach. These data were then analyzed in two ways: (1) by individual reach and (2) by all reaches combined using 2-sample t-tests at a 95% confidence level ($\alpha=0.05$). The results of these analyses are presented in Table 7 for aquatic drift, Table 8 for terrestrial drift, and Table 9 for total drift.

Table 7. Day and night mean densities and mean standard errors (SE) for drifting aquatic invertebrates in individual reaches and for all reaches combined. Blocked refers to estimates of drift density from nets 2 and 3. Control represents net 1, the net furthest upstream. Means were compared using 2 sample t-tests at a 95% level of significance ($\alpha=0.05$).

	All Reaches		LWC		UWC		TRIB	
	Day	Night	Day	Night	Day	Night	Day	Night
Blocked	1.58	4.07	0.71	3.28	1.81	5.14	2.01	3.89
SE	0.30	0.46	0.15	0.94	0.36	0.67	0.66	0.51
Control	1.91	7.85	0.59	3.91	3.93	10.75	1.22	7.57
SE	0.79	2.04	0.08	0.14	1.78	3.41	0.29	3.67
Significance	0.68	0.04	0.56	0.67	0.29	0.11	0.38	0.35

Table 8. Day and night mean densities and mean standard errors for drifting terrestrial invertebrates in individual reaches and for all reaches combined. Blocked refers to estimates of drift density from nets 2 and 3. Control represents net 1, the net furthest upstream. Means were compared using 2 sample t-tests at a 95% level of significance ($\alpha=0.05$).

	All Reaches		LWC		UWC		TRIB	
	Day	Night	Day	Night	Day	Night	Day	Night
Blocked	0.69	0.52	0.31	0.23	0.58	0.55	1.09	0.78
SE	0.16	0.12	0.10	0.04	0.18	0.12	0.31	0.30
Control	1.05	0.79	0.33	0.21	0.78	1.25	2.07	0.73
SE	0.51	0.20	0.08	0.12	0.15	0.34	1.52	0.20
Significance	0.47	0.23	0.88	0.82	0.46	0.09	0.49	0.90

Table 9. Day and night mean densities and mean standard errors for all (terrestrial + aquatic) drifting invertebrates in individual reaches and for all reaches combined. Blocked refers to estimates of drift density from nets 2 and 3. Control represents net 1, the net furthest upstream. Means were compared using 2 sample t-tests at a 95% level of significance ($\alpha=0.05$).

	All Reaches		LWC		UWC		TRIB	
	Day	Night	Day	Night	Day	Night	Day	Night
Blocked	2.27	4.59	1.02	3.51	2.40	5.60	3.10	4.67
SE	0.44	0.48	0.21	0.94	0.45	0.67	0.96	0.66
Control	2.97	8.67	0.49	4.12	4.71	12.0	3.29	8.30
SE	1.00	2.22	0.16	.031	2.18	3.71	1.84	4.43
Significance	0.50	0.04	0.72	0.69	0.28	0.10	0.92	0.38

Two patterns are evident from the drift blocking experiment. First, drift densities for all reaches combined were significantly lower ($p=0.04$) at night in the blocked reaches for the categories of aquatic drift (Table 7) and total drift (Table 9); no significant difference ($p=0.23$) in terrestrial drift density was noted (Table 8). These findings suggest that aquatic invertebrates drift longer distances at night. Second, there was a consistent trend toward reduced drift density at night in UWC for each of the three categories of drift: (1) aquatic ($p=0.11$), (2) terrestrial ($p=0.09$), and (3) total ($p=0.10$). The reduced variance associated with pooling the data from all the reaches perhaps best explains why significant reductions in drift density were found for all sites combined, but not for individual reaches. The trend toward reduced drift densities in UWC for all categories may be explained by the fact that UWC had the shortest distance between nets (Table 1b) and no intervening pools. Without the

presence of pools, invertebrates may have not been able to settle out of the current and therefore may have been transported a greater distance.

4. Conclusion

The purpose of this study was to gather baseline information on the drift community in the Upper Wine Spring watershed. To achieve this goal, the first objective of this study was to determine the taxonomic composition and abundance of the drift community. For the aquatic fraction, this was done to the genus level when possible. Most of the drift was composed of early instars, making genus level identification problematic for certain taxa. In addition, certain larvae in the order Diptera were challenging to identify even to the family level. In spite of these difficulties, 65 different types of drifting organisms were documented; 48 of these were various genera of larval aquatic insects. The percent composition of aquatic taxa was dominated by a few individuals: the mayfly *Baetis* accounted for nearly 50% of all aquatic taxa. Except for Collembola, the terrestrial fraction of the drift was categorized by general morphologic characteristics rather than taxonomic ones. Collembola and winged insects accounted for almost 90% of the terrestrial insect abundance.

The second objective of this study was to describe the diel periodicity of drift in terms of density and biomass. The density and biomass of the drifting aquatic taxa was significantly greater at night. There was no significant diel difference in terrestrial density or biomass.

The third objective of this study was to determine if there were any correlations between the drift and the physical structure of the stream. No significant relationship was identified for the aquatic

fraction of the drift. In contrast, the terrestrial fraction of the drift was negatively correlated with mean width of the stream: mean width explained 26% of the variance in terrestrial drift density.

The final objective was to determine if capturing the entire drift of the stream had a significant impact on the density of the drift at downstream locations. Significant reductions in nocturnal aquatic and total drift densities were identified. No significant reductions were found for terrestrial drift at night or any component of drift during the day.

This study seems to indicate that there is little excess food available in the form of drift to sustain additional invertebrate or trout production--although more research is clearly needed to validate this interpretation. In addition, the similar biomass of drifting terrestrial and aquatic invertebrates during the day indicates that terrestrial drift may be an important food resource for trout. To determine this, a comparison of the composition of drift with data on trout gut analyses may prove useful. Furthermore, the significant biomass of terrestrial invertebrates in the daytime drift also underscores the importance of maintaining a functional riparian zone as part of an ecosystem management strategy for minimizing impacts to the creek from forestry practices. Finally, since drift is in an important trophic pathway between insects and fish (Brittain and Eikland, 1988), this study should help forest service managers gage their ecosystem management objective of maintaining or increasing the productivity of insects and trout in the watershed.

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7. Appendices

7.1. Appendix 1. List of drifting aquatic invertebrates collected in Wine Spring creek and its unnamed tributary, Wayah Ranger District, Nantahala National Forest, North Carolina, June-July 1996.

1. Phylum: Annelida
 - a. Class: Oligochaeta
2. Phylum: Platyhelminthes
 - a. Class: Turbellaria
3. Phylum: Nematoda
4. Phylum: Arthropoda
 - a. Subphylum: Chelicerata
 - i. Class: Arachnida
 - (1) Subclass: Acari
 - b. Subphylum: Crustacea
 - i. Class: Copepoda
 - ii. Class: Malacostraca
 - (1) Order: Decapoda
 - (a) Family: Cambaridae
 - (i) *Cambarus sp.*
 - c. Class: Insecta

i. Order: Ephemeroptera

(1) Baetidae

(a) *Baetis sp.*

(2) Oligonuridae

(a) *Isonychia sp.*

(3) Heptageniidae

(a) *Epeorus sp.*

(b) *Stenonema sp.*

(c) *Rithrogena sp.*

(d) *Cinygmula sp.*

(4) Ephemerelidae

(a) *Drunella sp.*

(b) *Ephemerella sp.*

(c) *Serratella sp.*

(5) Leptophlebiidae

(a) *Paraleptophlebia sp.*

ii. Order: Odonata

(1) Suborder: Anisoptera

(a) Gomphidae

(i) *Lanthus sp.*

iii. Order: Plecoptera

(1) Pteronarcyidae

(a) *Pteronarcys* sp.

(2) Peltoperlidae

(a) *Tallaperla* sp.

(3) Nemouridae

(a) *Amphinemura* sp.

(b) *Soyedina* sp.

(4) Leuctridae

(a) *Leuctra* sp.

(5) Perlidae

(a) *Beloneuria* sp.

(6) Perlodidae

(a) *Yugus* sp.

(b) *Isoperla* sp.

(c) *Remenus* sp.

(7) Chloroperlidae

(a) *Sweltsa* sp.

iv. Order: Trichoptera

(1) Philopotamidae

(a) *Dolopholoides* sp.

(2) Polycentropodidae

(a) *Polycentropus* sp.

(3) Hydropsychidae

- (a) *Arctopsyche* sp.
- (b) *Diplectrona* sp.
- (4) Rhyacophiloidea
 - (a) *Rhyacophila* sp.
- (5) Glossosomatidae
 - (a) *Glossosoma* sp.
- (6) Brachycentridae
 - (a) *Brachycentrus* sp.
 - (b) *Micrasema* sp.
- (7) Lepidostomatidae
 - (a) *Lepidostoma* sp.
- (8) Sericostomatidae
 - (a) *Fattigia* sp.
- (9) Hydroptilidae
 - (a) *Hydroptila* sp.

v. Order: Coleoptera

- (1) Carabidae
- (2) Elmidae
 - (a) *Promoresia* sp.
 - (b) *Optioservus* sp.
 - (c) *Macronychus* sp.
- (3) Heteroceridae

(4) Staphilinidae

vi. Order: Diptera

(1) Blepharicidae

(a) *Blepharicera sp.*

(2) Tipulidae

(a) *Tipula sp.*

(b) *Hexatoma sp.*

(c) *Ormosia sp.*

(d) *Pedicia sp.*

(e) *Dicranota sp.*

(3) Ceratopogonidae

(4) Simuliidae

(a) *Simulium sp.*

(5) Chironomidae

(6) Dixidae

(a) *Dixa sp.*

(7) Athericidae

(a) *Atherix sp.*

(8) Empididae

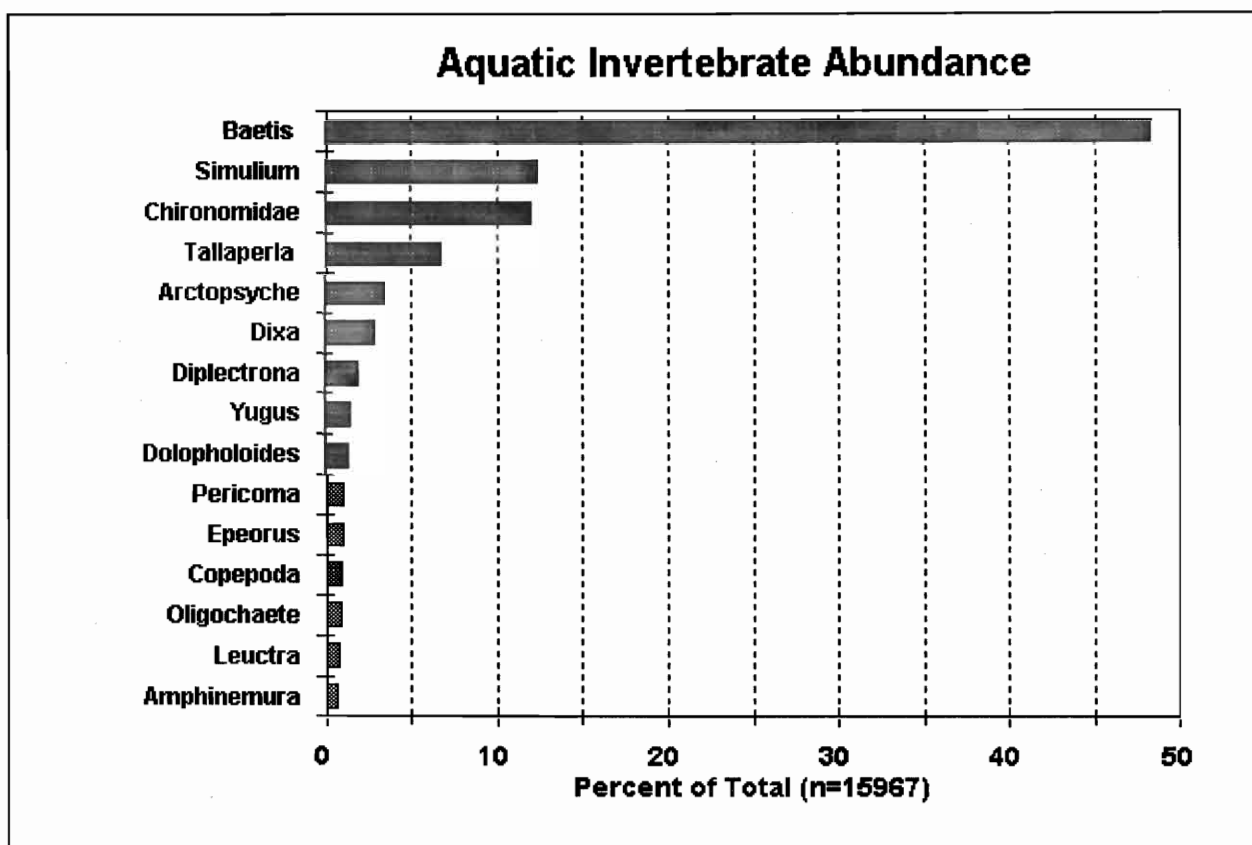
(a) *Chelifera sp.*

(9) Dolichopodidae

(10) Nymphomyiidae

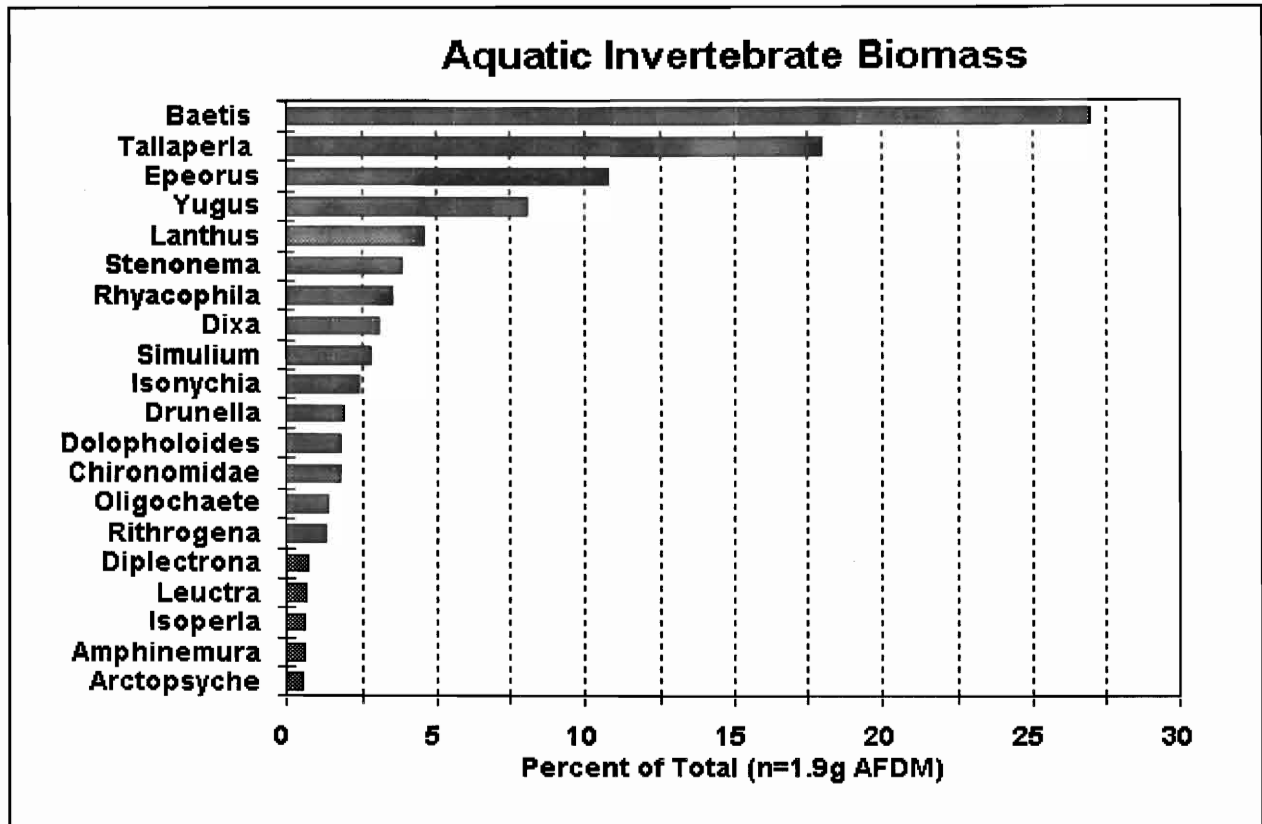
- (a) *Nymphomyia sp.*
- (11) Tabanidae
- (12) Tanypodinae
- (13) Psychodidae
- (a) *Pericoma sp.*
- (14) Thaumaleidae
- (a) *Thaumalea sp.*

7.3. Appendix 3. Taxa that accounted for 95% of the abundance of aquatic invertebrates from all sites.



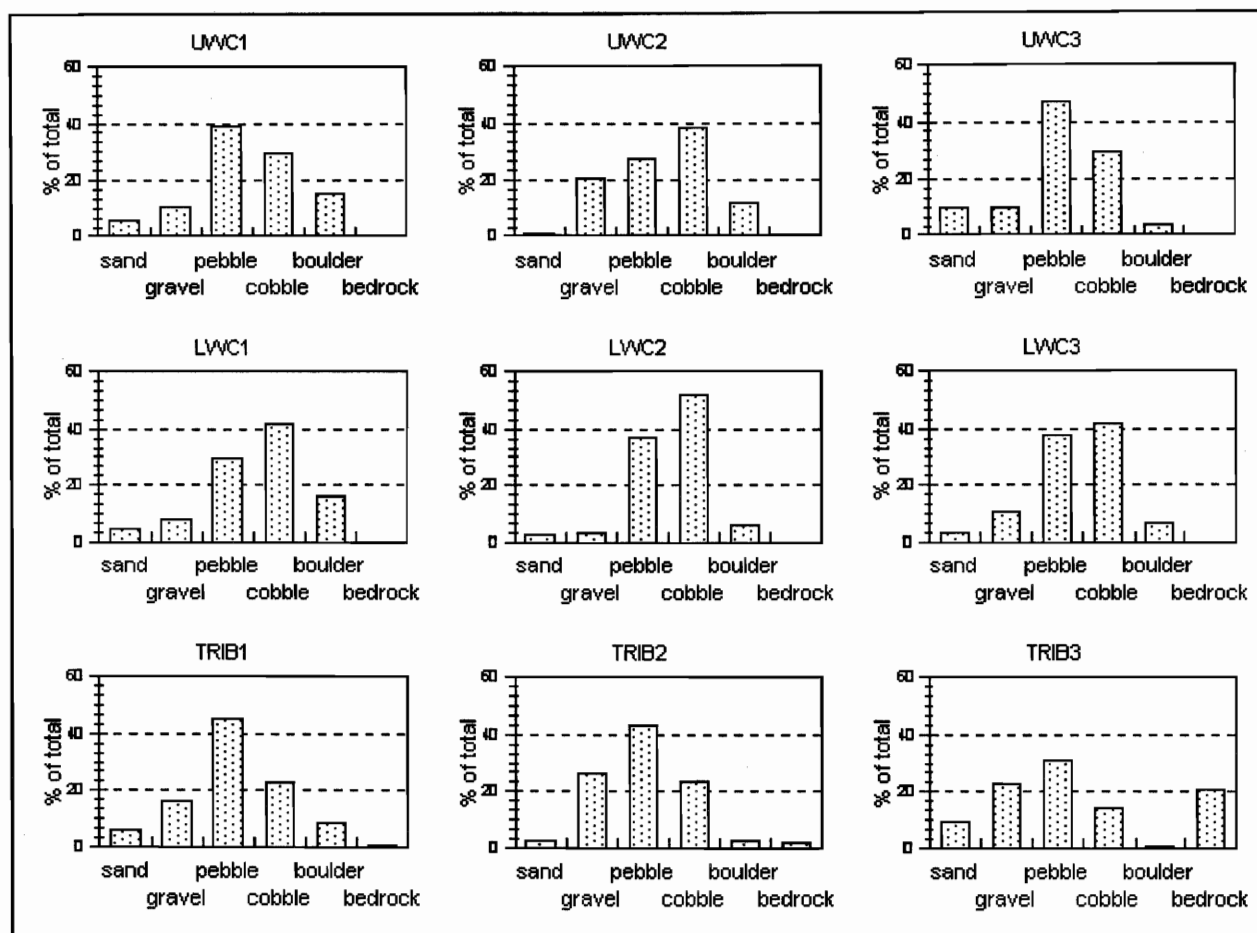
The x-axis represents the percent abundance of all aquatic invertebrates counted in this study. The y-axis shows the most abundant drifting invertebrates. These accounted for 95% percent of all invertebrates in the drift. Note the dominance of aquatic insects; oligochaetes were the only common aquatic invertebrates that were not aquatic insects.

7.4. Appendix 4. Taxa that accounted for 95% of aquatic invertebrate biomass from all sites.



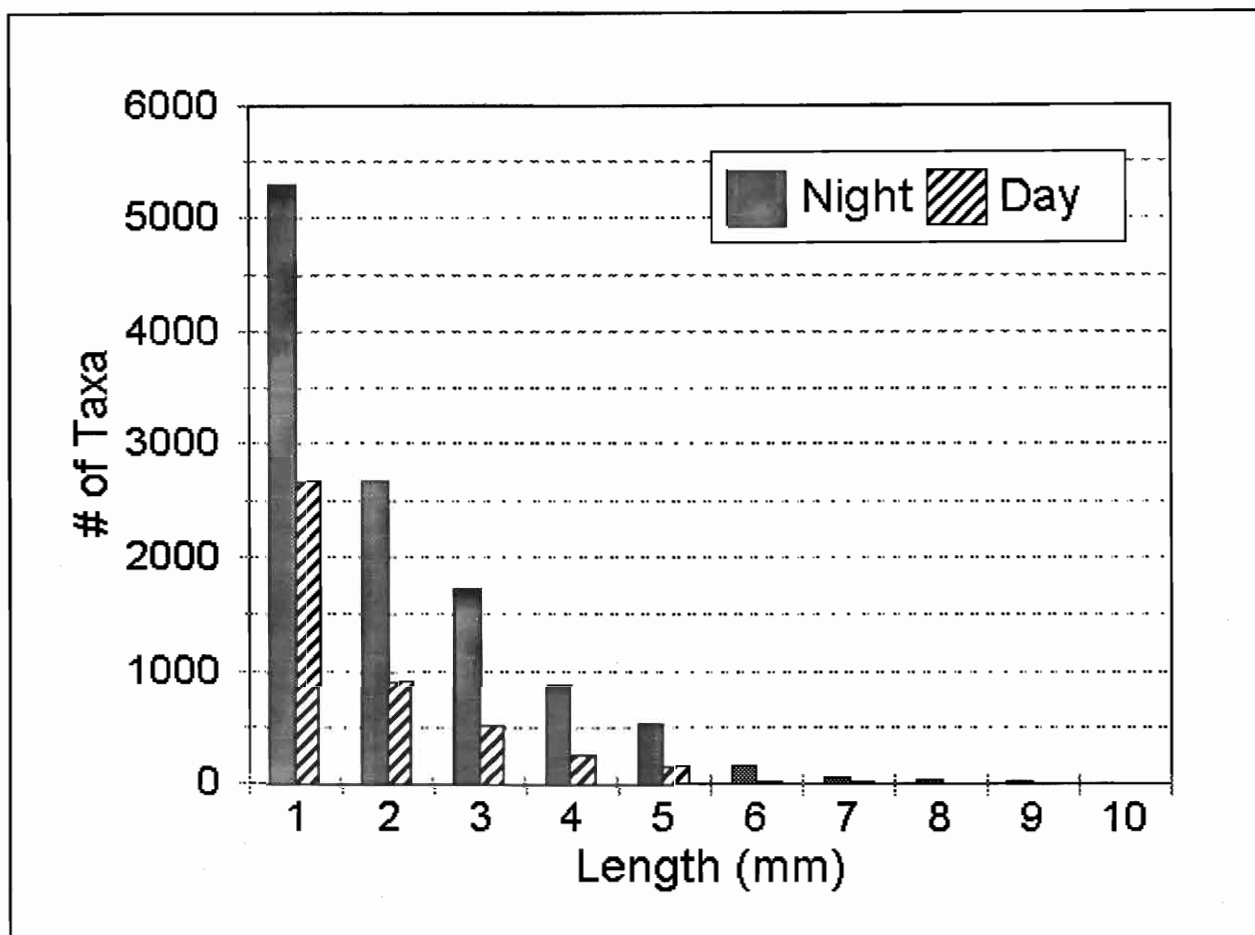
The x-axis represents the percent of total biomass for all aquatic invertebrates. The y-axis lists the invertebrates that accounted for 95% of the biomass of all the drift. Note this generally corresponds with Appendix 3; however, the dragonfly larvae *Lanthus sp.* was only found once in the drift--yet it contributed to nearly 5% of the total drift biomass.

7.5. Appendix 5. Percent composition of substrate for each study site.



Note that TRIB3 had greater than 20% bedrock; however, no difference in density or biomass was found between TRIB3 and the other study sites.

7.6. Appendix 6. Histogram of the length distribution of aquatic taxa for both night and day.



Drift was dominated by small taxa. The weighted mean length (both day and night) was approximately 2mm.

7.7. Appendix 7. Regression of terrestrial invertebrate density vs. stream width.

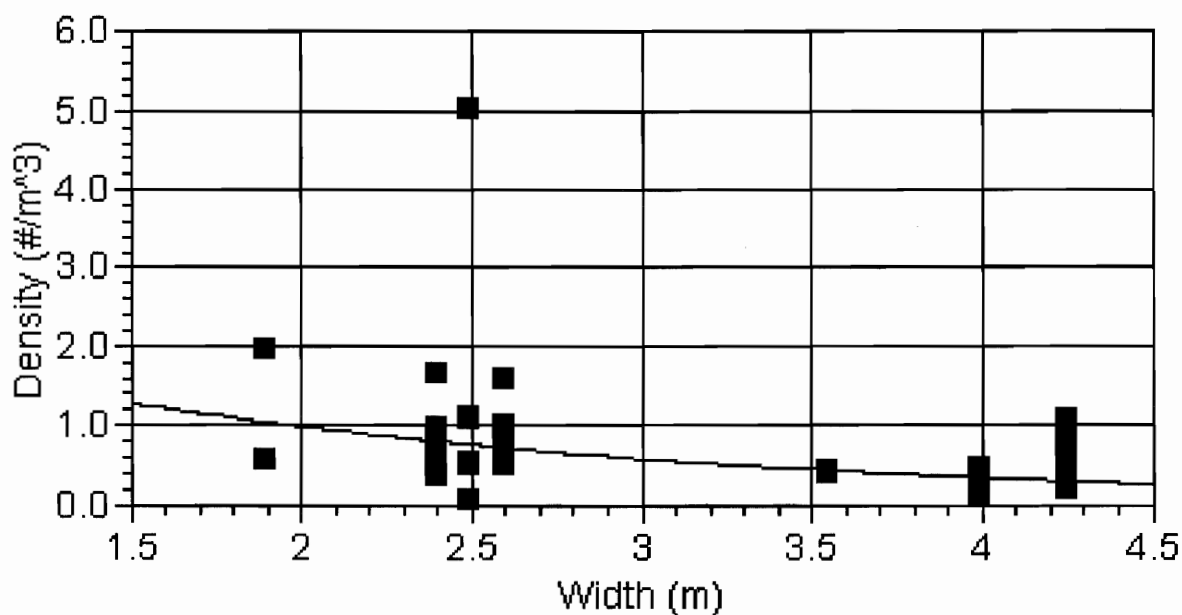


Figure A. Note the influential outlier. $r^2=0.26$.

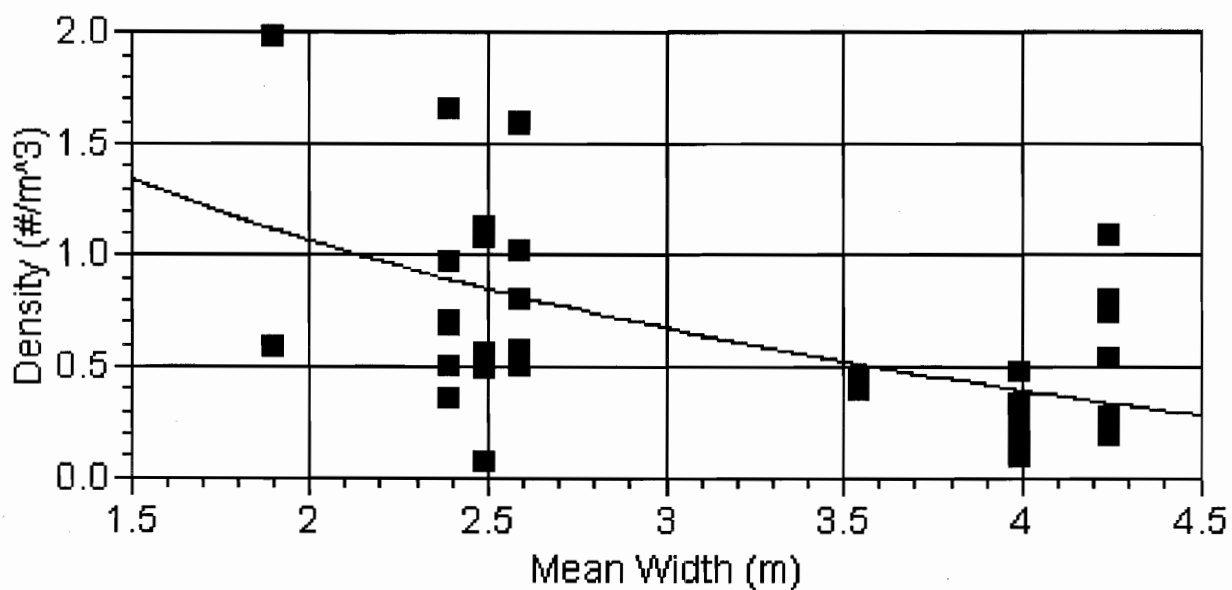


Figure B. Influential outlier in Figure A removed from calculations. $r^2=0.30$.