PHYSICAL-CHEMICAL AND BIOLOGICAL CHARACTERIZATION OF SMALL STREAMS FOLLOWING INTENSIVE FOREST MANAGEMENT PRACTICES IN THE COASTAL PLAIN OF ALABAMA

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Date of Graduation

VITA

Sergio Sigfredo Ruiz Córdova, son of Laura Córdova Corzantes and José Rómulo Ruiz Araujo, was born May 21, 1959 in Santa Cruz El Chol, Baja Verapaz, Guatemala. He attended Public Schools in Guatemala and graduated as an elementary school teacher from the Escuela Normal Rural No. 4 in 1976. In January 1978 he entered the Center for Marine Studies and Aquaculture (CEMA), branch of the San Carlos University of Guatemala, and received the diploma of Aquaculture Technician in December 1980. In January 1983 he enrolled in the School of Marine Sciences of the Autonomous University of Baja California Sur (UABCS) in Mexico and graduated with honors in June 1989 as a Marine Biologist. On January 1987 he married Mary Evelyn, daughter of Herbert E. and Carol S. Hawk and procreated two beautiful daughters Edith Alexandra and Judith Carolina. Sergio has been working with Alabama Water Watch and Global Water Watch since joining Auburn University in the spring of 1993.

THESIS ABSTRACT

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This study measured changes in five first-order streams (S 1 through S 5) following management techniques including clearcut logging and chemical (S 2 and S 3) and mechanical site preparation (S 4 and S 5). The herbicides used in this study included a mixture of Imazapyr and Glyphosate. Streams in two watersheds (S 3 and S 5) were left with 35-foot (11 m) wide streamside management zones (SMZ) while S 2 and S 4 had no SMZ. The fifth stream (S 1) draining an undisturbed watershed of similar size was used as a control. During each phase of the study (predisturbance, harvest and site preparation) periphyton, macroinvertebrates and physicochemical data were collected at least two times per season from August 1993 to December 1995. Statistical analyses utilized randomized intervention analysis (RIA). Pre-disturbance phase data showed similar seasonal variation among all streams regarding water temperature, dissolved oxygen and algal biomass, except for S 3 that was strongly influenced by springs. Water temperature in clearcuts with SMZ was not significantly different from the control while those without SMZ increased significantly following harvest. Among biological communities, when compared to the control stream, algal biomass (as chlorophyll *a*) from periphyton showed the greatest change and significantly increased in all streams after harvest, particularly in those with no SMZ. These changes probably resulted from the reduced canopy cover and increased sunlight reaching the streams because nitrogen and phosphorous changed little following harvest or site preparation. Following site preparation, chlorophyll *a* values remained high compared to the pre-disturbance phase. The herbicide had no apparent detrimental effect on periphyton biomass. Macroinvertebrate population densities were highly variable during the study period. Following harvest, macroinvertebrates in S 2 and S 4 with no SMZ had greater increases in density than that measured in the streams with SMZ. However, only in S 4 was this difference significant. This density difference probably reflected the increase in algal biomass in S 2 and S 4. After site preparation macroinvertebrate densities were unaffected when compared with the control using RIA. Taxa richness and diversity (i.e. both Shannon-Weaver and EPT) were not affected during harvest or site preparation according to RIA. Even with a 35-foot SMZ, timber harvest as practiced in the southeastern USA increased algal biomass as a result of additional light reaching the streams, especially streams with no SMZ. However, the presence of SMZ seemed to mitigate any dramatic changes to macroinvertebrate communities. Chemical and mechanical site preparation techniques did not significantly affect periphyton biomass and macroinvertebrate communities during this study. Timber harvest without SMZ appeared to be the management practice that most affected the stream biota.

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I. INTRODUCTION

This study was designed to detect certain physicochemical and biological changes in Coastal Plain first-order streams flowing through small watersheds exposed to traditional southeastern forestry techniques. The forestry practices utilized during harvest included use of stream management zones (SMZ) versus no SMZ; and following harvest, mechanical versus chemical site preparation prior to planting pine seedlings. To assess differences between these practices, physicochemical variables were measured in each stream along with changes in periphyton and macroinvertebrate communities.

A. Clearcut Harvest and Site Preparation

In the southeastern United States (US) intensive silviculture has contributed to forestry becoming one of the regions leading industries. Loblolly pine (*Pinus taeda L.*) plantations are the predominant type of silviculture practiced in the Southeast (Rosson 1995). Several approaches are used in intensive forestry but two, in particular, are of concern as potential sources of contaminants to streams. These two practices are clearcut harvest and site preparation prior to planting pine seedlings. Clearcutting creates areas of bare soil that, when exposed to rain, may result in erosion and sedimentation to local water bodies. Site preparation can also result in erosion and depending on the method used, may contribute runoff of pesticides to streams and lakes according to a 1993 study by the United States Environmental Protection Agency (US EPA).

Clearcutting generally involves removal of all trees larger than four inches in diameter (Bryce *et al.* 1989). Following harvest, the main purpose of site preparation is to reduce competition for light, moisture and nutrients between newly planted pine seedlings and unwanted vegetation. In addition, site preparation facilitates planting and enhances growth and survival of new trees.

Site preparation methods are categorized as follows: mechanical, chemical, and burning (Roth 1987). Mechanical preparation involves the use of heavy machinery, such as bulldozers with special attachments that directly remove competing vegetation, clears debris and incorporates organic matter into the soil. Consequently, large areas of bare soil are often exposed to rain and wind action. Chemical site preparation utilizes herbicides to reduce undesirable vegetation. Use of herbicides has become increasingly popular in recent years especially on steep slopes, because there is little soil disturbance. Chemical preparation is also less expensive than mechanical techniques (Roth 1987). The most commonly used herbicides in forestry in the Southeastern US are Accord®, active ingredient (ai) glyphosate; Arsenal AC® and Chopper®, (ai) imazapyr; Oust®, (ai) sulfometuron; Velpar L®, (ai) hexazinone; and Garlon 4®, (ai) triclopyr (Personal communication Dr. Bruce Zutter, School of Forestry, Auburn University, 1998). These herbicides are applied alone or as a mixture of two or more chemicals, depending on the plant species. Burning as a method of site preparation may be used exclusively, or as a supplement to either chemical or mechanical techniques (Roth 1987). Aerial applications of incendiary mixtures are the most common technique used in burning.

Harmful effects of these herbicides may persist in the watershed. Half-life of glyphosate was reported in a range from 2 to 174 days in soils and from 3.5 to 70 days in water (SERA 2003). Michael and Neary (1991) reported half-life for imazapyr in Alabama soils ranging from 19 to 34 days. Fowlkes *et al.* (2003) reported a half-life of 3.2 to 3.4 days for imazapyr in microcosms.

In numerous biological studies of stream periphyton communities increases in primary production occurred after logging (Hansmann and Phinney 1973, Gregory 1980, Murphy and Hall 1981, Lowe *et al.*1986, Murphy *et al.*1986). In streams without SMZ, Murphy and Hall (1981) found significantly higher periphyton densities from watersheds harvested 5 to 17 years earlier compared to undisturbed sites. Borg *et al.* (1988) also found a significant increase in algal blooms in streams from logged sites without SMZ, compared to streams with 100-m wide SMZ. However, Shortreed and Stockner (1983) concluded that physicochemical factors that were modified as a result of logging had little effect on periphyton communities because phosphorous levels were not generally affected. Kosinski and Merkle (1984) reported that glyphosate significantly inhibited alga photosynthesis. In contrast, Austin *et al.* (1991) suggested that glyphosate served as a nutritional source of phosphorous and stimulated increased periphyton growth in experimental streams. Imazapyr has been found to be more toxic to rooted and floating macrophytes than to other aquatic organisms, including algae (Roshon *et al.* 1999).

Logging operations during harvest also include disturbances such as road construction, log decks, skid trails and other activities that contribute to erosion and sedimentation in local streams (Bryce et al. 1989). Protecting stream quality from activities associated with intensive silviculture has gained increased attention by state and federal agencies. For example, the Alabama Department of Environmental Management (ADEM) and the US EPA require that forest operations be conducted in such a way that stream quality is not impaired (US EPA 1993; ADEM 1992). State agencies recommend the use of best management practices (BMPs) to maintain and protect the physical, chemical and biological integrity of waters (AFC 1993).

Clearcut harvest and site preparation have been shown to disrupt forest ecosystems (Noel *et al.* 1986; Campbell and Doeg 1989; Davies and Nelson 1994). Streams flowing through these disturbed ecosystems typically undergo five types of modifications. These include changes in discharge, water temperature, turbidity and sedimentation, dissolved nutrients and allochthonous organic detritus (Lynch *et al.* 1977).

Stream discharge often increases following canopy removal because water interception and transpiration on the watershed are severely reduced when trees are subtracted (Hornbeck *et al.* 1970, Aubertin and Patric 1974, Miller 1984). Significantly higher water yields have been reported from clearcut watersheds without SMZ (Beasley and Granillo 1988). Brozka *et al.* (1982) reported a 95% increase in flow volume in streams the first year after clearcutting but such effects have persisted even two years after harvest (Miller 1984). Abdul-Rahim and Harding (1992) concluded that SMZ help ameliorate hydrological impacts of logging on streamflow. They found that peak streamflow in clearcut areas without an SMZ increased 58% compared to a clearcut with an SMZ.

Water temperature in streams usually increases after a clearcut because of additional sunlight reaching the water (Burton and Likens 1973; Rishel *et al.*1982). After a timber harvest in West Virginia, mean summer temperatures increased 4°C with maximum temperatures increases greater than 9°C; while mean winter temperatures decreased by 2°C (Lee and Samuel 1976). SMZ mitigate these temperature fluctuations by providing cover to the stream (Rishel *et al.* 1982; Belt and O'Laughlin 1994). Davies and

Nelson (1994) found that stream temperatures increased 10% where SMZ widths were less than 10-m, while in streams with SMZ of 10-30 and 30-50-m, water temperatures were not significantly different from undisturbed streams.

Erosion and sedimentation is another common problem associated with clearcutting. Sediment yields in streams were found to increase after harvest and mechanical site preparation (Tebo 1955; Cordone and Kelly 1961; Brown and Krygier 1971; Bormann *et al.* 1974; Patric *et al.* 1984; McClurkin *et al.* 1985, Platts *et al.* 1989). Harvesting techniques also influence sediment losses from clearcut sites (McClurkin *et al.* 1985). A study conducted in the Coastal Plain of Arkansas compared sediment movement in streams from chemically and mechanically site prepared watersheds versus undisturbed ones. Mean annual sediment losses on mechanically site prepared watersheds (264 kg/ha) during the first post-treatment year were significantly higher than the mean of 4 kg/ha from undisturbed controls (Beasley *et al.* 1986; Beasley and Granillo 1988). Michael *et al.* (2000) suggested from research conducted in the upper Coastal Plain of Alabama that using herbicides properly during site preparation in combination with SMZ have the potential to reduce sediments reaching the streams.

Studies on nutrient levels in streams following clearcut have revealed differing results. Some studies have reported increases in nutrients to be negligible, or of short duration, following clearcuts (Aubertin and Patric 1974, Patric 1980, Martin *et al.* 1984); however, Brozka *et al.* (1982) found a 274% increase in nitrate (NO_3-N) concentration in streams following clearcut. Smith *et al.* (1988) found that chemical site preparation also resulted in significant increased concentrations of nitrate in streams in Maine. Manual applications of hexazinone pellets to a Piedmont watershed caused NO_3-N to exceed normal levels by two orders of magnitude 2-yr after treatment (Neary *et al.* 1986). Mechanical site preparation caused a 5-yr increase in nitrate concentration in groundwater in Finland (Kubin 1995). Blackburn and Wood (1990) found significant differences in nitrogen and phosphorous in streams with SMZ 6-20 m wide and mechanically site prepared, compared to undisturbed streams. Patric (1980) suggested that a 20-m wide SMZ minimized water quality effects, while in treatments without an SMZ nitrate levels increased five-fold during the first year after disturbance. Lowe *et al.* (1986) suggested that light was the factor limiting algal accumulation in forested watersheds after experimental additions of nutrients to streams.

Clearcuts also alter the quantity, quality and timing of allochthonous organic matter introduced to streams. Gurtz and Wallace (1984) found significantly higher amounts of woody material in streams draining logged watersheds compared to undisturbed ones.

B. Streamside Management Zones

One of the primary forestry BMPs suggested by states to reduce runoff of soil and chemicals to streams and lakes include leaving riparian forests or streamside management zones (SMZ) along these water bodies to protect aquatic ecosystems and water quality (Michael 2004). SMZ are also referred as “buffer strips” (Belt *et al.* 1992). In Alabama the suggested minimum standard width of an SMZ is 11-m (35 feet) from a definable bank (Alabama Forestry Commission 1993) and 15-m (50 feet) minimum if wildlife protection is a major objective. Also, SMZ width should increase 6-m (20 feet) for each 10% increase in slope (Brinker 1989).

Riparian forests are vegetative zones along streams that serve as complex ecosystems. These zones provide allochthonous organic materials (leaves and woody debris) that help maintain the biological productivity and diversity of streams (Gurtz *et al.* 1980; Murphy *et al.* 1981; Webster and Waide 1982; Webster *et al.* 1983; O'Hop *et al.* 1984; Andrus *et al.* 1988; Carlson *et al.* 1990). Logs, branches and leaves also create habitat for stream organisms (Sweeney 1993). SMZ are useful in mitigating or controlling non-point source pollution by capturing sediment from surface runoff (Brown and Krygier 1971, Brown 1971; Newbold *et al.* 1980; Hawkins *et al.* 1982; Gurtz and Wallace 1984; Welsch 1991; Comerford *et al.* 1992). SMZ are also effective in removing nutrients (Hill 1996; Johnson *et al.* 1996), reducing the amount of herbicide reaching streams (Michael 2004) and providing shade to cool the waterbody, thus helping maintain light and temperature conditions for stream biota.

C. Herbicides, Silviculture and Aquatic Biota

Herbicides used in site preparation have been shown to contaminate ground and surface water and can be toxic to aquatic invertebrates and fish (Swadener 1993; Cox 1996, 1998). However, most toxicity studies have been conducted in the laboratory under controlled climatic conditions (Kosinski and Merkle 1984, Austin *et al.* 1991) or in experimental stream channels through which flow is carefully controlled (Kreutzweiser *et al.* 1992, Schneider *et al.* 1995). The organisms used in these studies were exposed to constant levels of the herbicides during established time periods. Field studies do not provide this type of exposure for organisms. Limited field studies were found that tested the toxicity to aquatic biota of the herbicides typically used in intensive silviculture practices (Mayack *et al.* 1982, Michael *et al.* 1999, Fowlkes *et al.* 2003). Michael et al. (1999) concluded that benthic macroinvertebrates in Piedmont streams of the

Southeastern United States appear insensitive to hexazinone at the exposures observed in their study.

Accord® (a. i. imazapyr) and Arsenal AC® (a. i. glyphosate) were the herbicides used for chemical site preparation in this study. Fowlkes *et al.* (2003) found that a concentration of imazapyr 100 times the expected from typical application rates did not affect *in situ* microcosm macroinvertebrate communities. In addition to herbicide toxicity, concerns exist that 50% or more of the herbicides used in site preparation such as glyphosate include inert ingredients that may be more toxic than the active ingredient (SERA 2003). Formulations of Accord® and Arsenal AC® contain more than 50% inert ingredients (USDA Forest Service 1995a, 1995b).

Accord® and Arsenal AC® in concentrations typically used in forestry are considered practically non-toxic to freshwater fish and aquatic invertebrates (USDA Forest Service 1995a, 1995b); even though concentrations of glyphosate between 3 and 25 ppm were lethal for the crustacean *Daphnia pulex* (Folmar *et al.* 1979, Servizi *et al.* 1987, Hessen *et al.* 1994). In addition, Hartman and Martin (1984) found that glyphosate concentrations of more than 1-mg/L significantly reduced *D. pulex* populations, mainly due to mortality of immature stages. Another aquatic invertebrate, the red swamp crawfish *Procambarus clarkii*, showed a 96-h LD50 when exposed to 47.3 mg/L of glyphosate (Holck and Meek 1987).

Forestry herbicides also affect aquatic vegetation. Glyphosate concentrations greater than 9 mg/L resulted in 50% photosynthetic inhibition of periphytic algae in small ponds (Goldsborough and Brown 1988). Peterson *et al.* (1994) in a study of periphyton communities, reported inhibition of carbon uptake in diatoms in the presence of glyphosate. The green alga, *Selenastrum capricornutum,* exhibited growth inhibition after 96-h exposure at concentrations of 5,300-5,500 mg/L of imazapyr as well as with 2,600 mg/L of glyphosate (Thomas *et al.* 1990).

Considering the natural undisturbed state present in the Camden watersheds at the beginning of this study, macroinvertebrate communities were expected to resemble that described by the River Continuum Concept (RCC) for small-undisturbed headwater streams. The RCC describes a continuous gradient in the distribution of organic matter and macroinvertebrate functional groups from headwater to mouth (Vannote *et al.* 1980). According to the RCC, small headwater streams are narrow and generally well shaded by the riparian canopy. Thus insufficient light may reach the streambed to promote algal growth and nutrients may be low. Since the stream does not produce enough energy to supply the demands of organisms, allochthonous energy becomes critical and enters the stream in the form of coarse particulate organic matter (CPOM) from the terrestrial environment. In headwater streams, leaf-shredding macroinvertebrates often constitute a large portion of the macroinvertebrate population, thus shredders and collectors are usually abundant. Grazers, macroinvertebrates that scrape algae from rock surfaces, are often low in abundance in headwater streams because insufficient sunlight reaches the channel thus resulting in a scarcity of algae. Predators should be common throughout the river system and can be found in headwaters, in smaller proportion relative to organisms of other feeding types.

Increased numbers of aquatic insects have been found following clearcuts (Newbold *et al.*1980, Murphy *et al.*1981, Carlson *et al.*1990) even 5 to 10 years after harvest, as well as changes in macroinvertebrate diversity and biomass (Murphy *et al.*1981, Duncan and Brusven 1985). Apparently, changes in the insect populations were a result of shifts in the food base after the disturbance. Davies and Nelson (1994) found an 80% decrease in macroinvertebrate abundance in logged sites with SMZ smaller than 30 m, and Newbold *et al.* (1980) found higher densities of tolerant macroinvertebrate taxa and lower diversities in reaches without SMZ. SMZ provided protection from intensive silvicultural practices because macroinvertebrate communities in California streams with SMZ wider than 30-m could not be distinguished from those of undisturbed reference streams in terms of diversity, similarity or density (Newbold *et al.* 1980). In addition, Boschung and O'Neil (1981) concluded that the aquatic macroinvertebrate community structure in an east Alabama stream was not affected following clearcuts as prescribed by the US Forest Services standards including SMZ.

The purpose of my study was to quantify changes in stream quality associated with intensive forestry practices used in pine regeneration. Water quality, periphytic algae and benthic macroinvertebrate communities were examined in five first-order streams prior to disturbance. Changes in these variables were measured during clearcut harvest and site preparation to determine any physicochemical and biological impacts of the disturbance. Changes were examined in streams with an SMZ and in streams without an SMZ. In addition, chemical versus mechanical site preparation techniques were compared for differences in impacts to the biota.

II. MATERIALS AND METHODS

A. Study Site

This study was conducted between 1993 and 1995 at the Alabama Agricultural Experiment Station, Lower Coastal Plain Substation, located in Wilcox County about 2.5 km north of the city of Camden, Alabama. Five small, topographically well-defined watersheds (W1…W5) were identified, each drained by a perennial first-order stream (Figure 1).

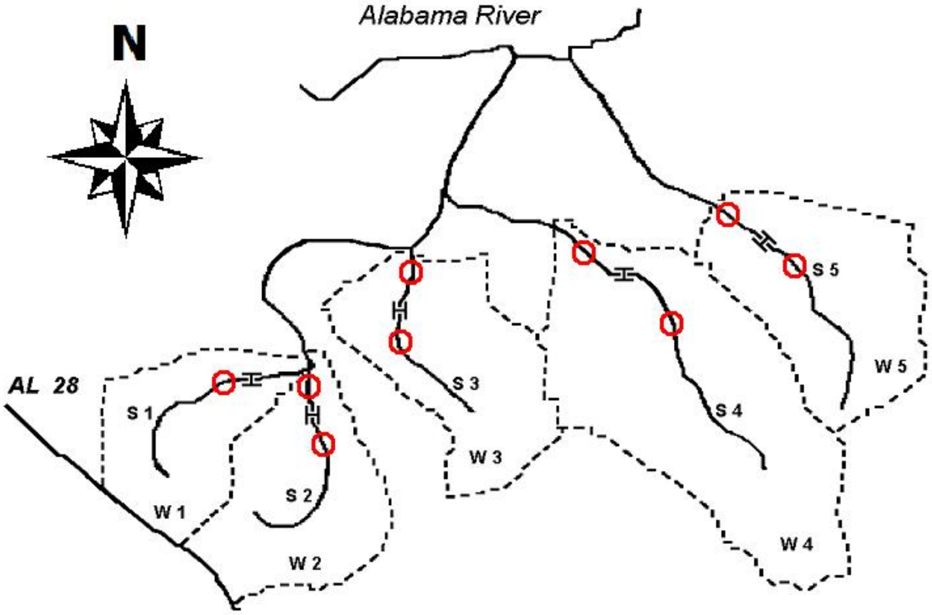

Figure 1. Diagram of the five watersheds and streams of the Camden Study, in Wilcox County, Alabama. Solid lines are the streams, dotted lines are the watershed boundaries, circles are the approximate location of sampling sites and each H represents a flume placed at the lower boundary of each clearcut. Sampling sites were located upstream and downstream from flumes in experimental streams.

Smithdale and Bama soils, derived from marine and fluvial sediments eroded from the Appalachian and Piedmont plateaus, are characteristic of these lower Coastal Plain areas. These soils have loamy subsoil and a sandy loam surface layer with slopes less than 5% (Brannon 1998). Sweetgums (*Liquidambar styraciflua*), eastern hop hornbeam (*Ostrya virginiana*), elms (*Ulmus* spp.), hickories (*Carya* spp.) and maples (*Acer* spp.) dominated the tree populations on the watersheds. Loblolly pines (*Pinus taeda*) dominated the basal areas with scattered oaks (*Quercus* spp), magnolias (*Magnolia* spp.) and poplars (*Liriodendron tulipifera*) among others (Marshall 1999). The streams were unnamed tributaries of the Alabama River, and William Dannelly Reservoir, and will be referred as S1, S2, S3, S4 and S5. All streams were about 1-m wide with small reaches approaching 2 to 3-m in width. Water depth ranged from less than 5-cm where the streambed was wide, to about 30-cm in pool areas where the channel was narrow. Each stream was typical of small-undisturbed Coastal Plain streams as described by Smock (1988). Trees grew to the banks of each stream and the forest canopy was dense. Allochthonous materials of leaves and other vegetative debris were the main energy inputs to the streams as expected based on the RCC. Stream habitats consisted mainly of shallow pools, runs of loose shifting sand and riffles of mostly gravel, sand and some cobble. Steep-sided mud banks were typical along most of the streams.

B. Experimental Design

Studies prior to disturbance were initiated in August 1993. By December 1994 each stream had been gaged with an H-flume placed near the downstream edge of the clearcut in each watershed (Figure 1). In S1 the flume was placed just upstream from confluence with S2. Flumes were equipped with air and water temperature probes, Keller

PSI pressure transducers, Campbell CR10 data loggers and ISCO 3700 automatic water samplers. Stream velocity, total discharge, water temperature and nutrients data were obtained from these automatic samplers. Rain gauges were placed in the middle of each watershed to record precipitation. Scientists from the USDA Forest Service installed the flumes, collected the physicochemical data and conducted the herbicide analysis.

Intensive forestry practices were applied to four of the watersheds (W2, W3, W4 and W5). The fifth watershed (W1) was used as a reference and left undisturbed. Two different experimental treatments were applied to the watersheds receiving clearcuts. Two streams were left with a 35-foot (11-m) wide SMZ while two streams had no SMZ. In addition, as preparation before planting pine seedlings, two watersheds received chemical site treatment and two watersheds were mechanically site prepared (Table 1).

A single sampling station (1c) was located in the reference stream upstream of the flume. Two stations were established in each of the other four streams; one inside the clearcut area above the flume (2a, 3a, 4a and 5a), and one downstream from the flume (2b, 3b, 4b and 5b). Each station included a stream reach of about 100-m. Streams were sampled twice per season from August 1993 to December 1995.

Table 1. Experimental design and watershed characteristics of the study area.

Watershed	Total Area (ha)	Clearcut (ha)	SMZ	Site Preparation
1	16.6	N/A	N/A	N/A
2	20.2	14.4	No	Chemical
3	18.6	14.4	Yes	Chemical
4	50.2	14.8	No	Mechanical
5	26.2	13.4	Yes	Mechanical

During February and March 1995 a commercial logger harvested timber from W2, W3, W4 and W5 using a circular saw head-feller buncher, rubber-tired skidders and a deck loader. Between 17 and 21 August 1995, W4 and W5 were mechanically site prepared using crawler tractors with a root rake. Small trees and shrubs less than 4-inch in diameter were sheared and pushed into windrows. On 30 August 1995, W2 and W3 were chemically treated with a mixture of Arsenal AC®, a.i. imazapyr [2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid] and Accord®, a.i. glyphosate [N-(phosphonomethyl)glycine], in the form of its isopropylamine salt. Labeled rates of Arsenal AC®, Accord® and a surfactant were mixed to provide an equivalent of 1.12-kg/ha of imazapyr, 3.36-kg/ha of glyphosate and 0.28-kg/ha of non-ionic surfactant. The herbicide mixture was applied by helicopter using a microfoil or TVB spray system to help ensure accurate application and minimum drift. On 21 November 1995, a prescribed burn was conducted on the four harvested watersheds using an incendiary mix dropped from a helicopter with an aerial drip torch, and on the ground using hand held drip torches. Each clearcut was planted with loblolly pine in January 1996.

C. Field Measurements

In addition to physicochemical measurements collected from water at each flume, from August 1993 to December 1995 the following data were collected. Water temperature and dissolved oxygen (DO) were measured *in situ* at each station using a model 51B Yellow Spring Ohio (YSI) Dissolved Oxygen meter. Canopy cover was measured as a percentage using a spherical densiometer (Lemmon 1957). Streams were sampled for periphyton and macroinvertebrates at least one week after heavy rains to allow those communities to recover from any scouring effects that might have resulted from the increased discharge. Quantitative samples of periphyton and benthic macroinvertebrates were collected using PVC core samplers developed in the Auburn University Laboratory by Dr Cliff Webber and me. Cores have one end beveled to allow easy insertion into the stream bottom and their small size makes them appropriate to obtain a quantitative periphyton sample easier than using a dredge or Ponar sampler. Three periphyton samples were collected from randomly selected riffles at each station by inserting a 50-mm inner diameter core sampler (area = 0.002 m^2) into the substrate to a depth of about 2-cm. While firmly holding the corer in place, an acrylic plate was inserted under the PVC sampler to prevent loss of the sample. The sample was lifted from the streambed and placed inside a labeled plastic Ziplock® bag. Each sample was stored in the dark on ice for transport to the laboratory.

Three macroinvertebrate samples from riffles and three from pool areas were collected at each station by inserting a 77-mm inner diameter core sampler (area = 0.005 m^2) into the substrate to a depth of about 10-cm. An acrylic plate was inserted under the PVC sampler to prevent loss of the sample as it was lifted from the streambed and placed into a galvanized bucket. Riffle and pool habitats were randomly selected from the stream reach at each station. During the predisturbance phase of the study macroinvertebrates were separated in the field from sediment and debris by elutriation. Six times water was added to the bucket, vigorously swirled and the water and organisms poured through a U.S. Standard No. 60 sieve (250-µm mesh). Samples were stored in ice chests for transport to the laboratory where they were refrigerated overnight at 4°C. Estimates of the substrate composition at each station were added to the sampling protocol during the experimental phase of the study. This included one date prior to clearcutting and all remaining dates.

In 1995, two of the three macroinvertebrate cores from riffles and two from pools were placed directly in plastic bags and returned to the laboratory for elutriation and analysis of substrate composition. Macroinvertebrates were elutriated in the field from the third sample from each habitat type. Sampling in 1995 included two dates before harvest, four dates between harvest and site preparation, and two dates after site preparation.

D. Laboratory Procedures

1. Substrate Composition and Benthic Organic Matter

After macroinvertebrates were elutriated from the samples, visual estimates were made of the percent composition of particles from the remaining substrate. The substrate material was evenly spread over the bottom of the bucket and estimates were made of the proportions of silt (< 0.06 mm), sand (0.06-2.0 mm), gravel (2.0-16 mm), pebble (16-64 mm) and cobble (> 65 mm). In addition, benthic organic matter (BOM) was measured from each sample. Three categories of BOM were measured using methods described by Golladay *et al.* (1989): woody debris (WD), particles 1-cm^2 and larger; large benthic organic matter (LBOM), particles retained by a No.18 sieve (1-mm mesh); and fine benthic organic matter (FBOM), the material retained by a No.60 sieve (250-µm mesh). Samples were poured through a No.18 sieve stacked onto a No.60 sieve. Leaves, seeds and twigs (WD) were manually separated and placed in a plastic container with the station identification. The materials retained by the No.18 and No.60 sieves were separated into individual containers labeled LBOM and FBOM, respectively.

Samples of BOM were dried to a constant weight in an oven at 103°C - 105°C for 1.0 hour and dry weight was determined using an analytical balance. Samples were then incinerated in a muffle furnace at 500°C for 60 minutes. Ash was rewet with distilled water after it cooled in a desiccator, and then brought to a constant weight at 103 to 105°C to estimate the ash free dry mass (AFDM). Dry weight and AFDM were calculated as a percentage of the sample for WD, LBOM and FBOM following Standard Methods (APHA 1995). Mean BOM was estimated for each station.

2. Periphyton

Pigment extraction and sample handling was conducted in subdued light to avoid degradation of chlorophyll. In a refrigerator samples were allowed to settle overnight to concentrate algae by sedimentation. The following morning excess water was siphoned from each bag and 30 ml of 90% alkaline acetone was added. Samples were refrigerated for 24-h at 4°C in the dark and vigorously shaken every two hours to disrupt algal cells and facilitate pigment extraction. After 24-h the chlorophyll extract was poured into tubes and centrifuged for 20 minutes at 500 g and 4°C to remove sediment and debris. Optical density (OD) of each sample was measured at 630, 647 and 750 nanometers using a Beckman DU-50 Series Spectrophotometer. The chlorophyll content of periphyton was determined to estimate algae biomass following the trichromatic method (APHA 1995). Chlorophyll *a* concentration was determined for each replicate using the formula:

$$Ca = 11.85*(OD664) - 1.54*(OD647) - 0.08*(OD630)$$

where 11.85, 1.54, and 0.08 are correction factors, and OD630, OD647, and OD664 are the corrected optical densities (with a 4-cm light path) at the respective wavelength. The amount of pigment per unit area was calculated using the formula:

$$\text{mg chlorophyll } a/\text{m}^2 = (\text{Ca} * 0.03)/0.002$$

where Ca is the chlorophyll *a* concentration in the extract; 0.03 is the volume of the extract in liters, and 0.002 is the surface area of the core sampler in m².

3. Macroinvertebrate Communities

Within 24 hours of collection, macroinvertebrate samples were preserved in 5 to 10% formalin for several days. Samples were then washed through a No. 60 sieve and rinsed with water to remove the formalin. Remaining debris and organisms were stored in 70% ethyl alcohol. Macroinvertebrates from all samples were sorted and counted using a stereomicroscope. Macroinvertebrates were identified to the lowest practical level (usually genus) using standard taxonomic keys (Merritt and Cummins 1996; Wiggins 1996; Edmunds *et al.* 1977; Bednarik and McCafferty 1979; Stewart and Stark 1988; and Wiederholm 1983). Macroinvertebrates were sorted into two categories, the "Chironomidae", midges in the Order Diptera, and "Others", the other categories included all other insects besides the midges and the miscellaneous invertebrates from each sample.

When known, macroinvertebrates were also assigned to a functional feeding group (FFG) based on classification by Merritt and Cummins (1996). The following categories were included: filtering collectors (FC), gathering collectors (GC), scrapers (SC), shredders (SH), predators (P) and piercers (PI). Densities for each core sample were expanded to number of organisms per m². The total number of taxa (taxa richness) was calculated for each sample as well as the EPT index, based on the number of taxa within the orders Ephemeroptera, Plecoptera and Trichoptera (Plafkin *et al.* 1989). Streams with a high EPT richness are considered in better condition than those with lower EPT richness since aquatic stages of these organisms are more sensitive to pollution. The diversity of macroinvertebrate communities was calculated using the Shannon-Weaver index (H') (May 1975). The formula used was:

$$\mathrm{H} = -\sum_{i=1}^{S_T} p_i \ln p_i$$

where p_i is the proportion of individuals in the *i*th species, $p_i = N_i/N_T$.

Densities for each core sample were compiled for "Chironomidae" and "others" for all seventeen sampling dates between August 1993 and December 1995 and expanded to number of organisms per m^2. Macroinvertebrates from pool and riffle habitats were combined for analysis of total densities. Analysis of taxa richness, community structure and diversity was conducted for selected dates that included four dates before harvest, two dates between harvest and site preparation and two dates after site preparation.

4. Nutrients and Herbicide Analyses

Nitrogen, phosphorous and herbicide concentrations from each watershed were analyzed by the USDA-FS Southern Forest Experiment Station at Auburn University using the water samples collected in the flumes from December 1994 to December 1995. Ten-ml aliquots were processed using a Dionex® ion chromatograph to quantitatively determine concentrations of nitrates (NO_3) and phosphates (PO_4). Off-site movement of imazapyr from the clearcut to streamflow was determined from water samples by high performance liquid chromatography (HPLC). Most methods for analyzing glyphosate, like the EPA method 547, are very expensive, time consuming and require specialized equipment. Therefore, no tests were conducted to analyze this herbicide.

5. Statistical Analysis

Calculations for each replicate were averaged to conduct the statistical analysis. These variables were used to evaluate macroinvertebrate differences among the sites, before and after harvest, and before and after site preparation. Values for the replicates from each station were averaged and analyzed statistically. The nature and scale of this study qualified it as a whole-ecosystem experiment and replicating whole ecosystems is seldom possible. A statistical method designed to address such experiments is Randomized Intervention Analysis (RIA). This method detects changes in a "manipulated ecosystem" relative to an undisturbed reference ecosystem (Carpenter *et al.* 1989). RIA indicates whether a change has occurred or not, however it does not demonstrate that the disturbance was the cause of the change. Parallel observations from the reference and manipulated streams were paired in time spanning periods before and after disturbance. A computer program designed for RIA (Carpenter *et al.* 1989) analyzed all measurement means. When data did not fit the RIA program, a Tukey's test was used to statistically compare differences among means with a probability $\alpha = 0.05$ for all tests of significance. Chlorophyll *a* and macroinvertebrate data values were logarithmically transformed [$\log_{10} (X_i + 1)$] in order to stabilize variance (Zar 1984). The biological and physicochemical measurements collected between August 1993 and February 1995 provided the pre-disturbance database that was compared against the same variables measured during post-harvest (March to August 1995) and post-site preparation (September to December 1995).

III. RESULTS AND DISCUSSION

A. Canopy Cover

Watersheds in this study had not been harvested for many years so at the beginning of this study all streams had a dense canopy consisting of a diverse riparian flora. Canopy cover prior to harvest was close to 100% in all streams, decreasing in the fall and winter to about 60% as hardwoods shed their foliage (Figure 2).

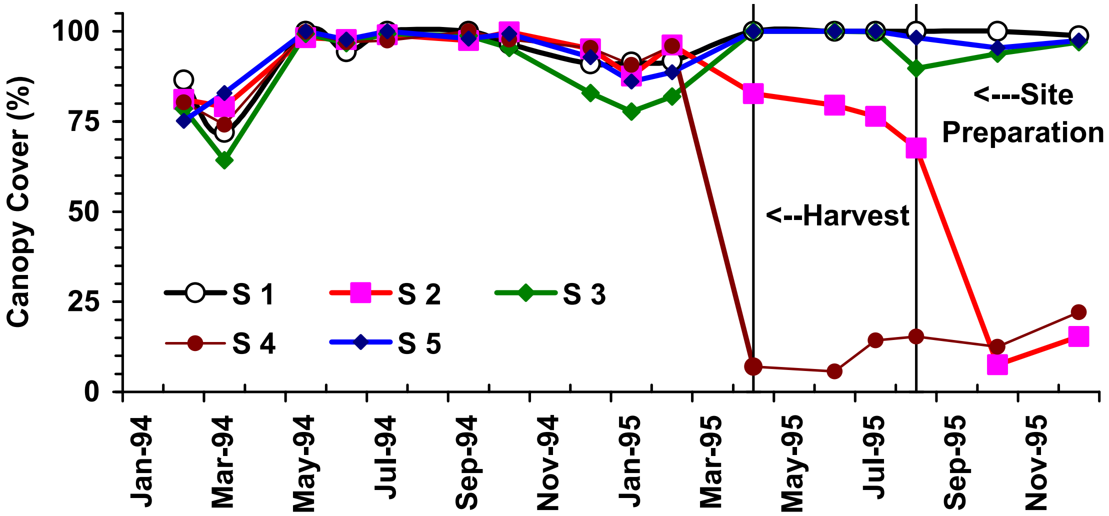

Figure 2. Mean percentage canopy cover from February 1994 through December 1995 in the reference stream and inside the clearcut area of four experimental streams in the Camden study.

After harvest the percent canopy cover in S 4 with no SMZ was reduced to about 10% within the clearcut areas, significantly less than that in the two watersheds with an SMZ (S 3 and S 5) and the reference stream (S 1). In S 2 (No SMZ) the decrease in canopy cover was gradual because steep slopes near the stream banks prevented mechanical harvest of many trees. Thus, no significant differences in canopy cover were found between S 2 and S 1 in the weeks following harvest. Several weeks later trees greater than four inches in diameter were manually harvested from the S 2 watershed allowing a complete clearcut similar to that on W 4. Stream 4 had no steep banks so trees greater than four inches in diameter were harvested to the edge of the stream. After harvest, canopy cover in S 3 and S 5 with SMZ ranged between 3 and 15% less than that measured in S 1, but significant differences were not detected among the three watersheds. These data suggested that an ~11-m SMZ was sufficient to mitigate increases in solar radiation reaching low order streams flowing through a clearcut. During the following spring and summer after harvest, vegetation within the clearcuts began growing in each watershed. Shrubs, grasses and vines were present by mid-summer on the watershed of each stream.

Chemical site preparation within the harvested area on W 2 and W 3 killed all forms of vegetation in August 1995. Riparian vegetation along the stream banks of S 2 was eliminated creating significant differences in canopy cover between S 2 and S 1 that persisted through the end of the study. Riparian vegetation within the SMZ along S 3 remained undisturbed following the herbicide application. Mechanical site preparation within the clearcuts on W 4 and W 5 did not significantly affect percent canopy cover. New grown riparian vegetation along S 4 was not disrupted by the treatment, and S 5 was protected by the SMZ. However it will probably take years for the canopy cover along S 4 to return to conditions similar to those present prior to harvest.

After harvest, from June to August 1995, water tables in the watersheds dropped following a long period of high air temperatures (*mean* =34°C) and little precipitation (e.g. 30-mm in June). Because of the small size of these watersheds, no surface flow was evident in S 1 during this time period. Similar conditions occurred in S1 during September 1994 but for a shorter period of time. Climatic conditions plus evapotranspiration by trees on the undisturbed watershed apparently led to the dry streambed. Flow was present in all of the other streams throughout the study. Values for water temperature in S 1 were generated for the dates when the stream was dry. Multiple regressions of air and soil temperatures on mean water temperature from the site were used to calculate these values (r^2=0.9, n= 51) (Stoneman and Jones 1996, Livingstone and Lotter 1998). Linear regression of water temperatures measured *in situ* on each sampling date and those measured through the flumes were also highly correlated (r^2=0.9, n=17).

B. Water Temperature and Dissolved Oxygen

Solar radiation was not measured in this study. However, because the small nature of the watersheds it was expected that the angle of the sun had similar effect on each watershed and each stream, therefore differences may be the effect of treatments. In all streams except S 3 water temperatures during the pre-disturbance period ranged from a low of 4°C in the winter to a high of 25°C in the summer (Figure 3). The range of water temperatures in S 3 during this period was not as wide as that in the other streams. The lowest temperature recorded in S 3 was 15°C during the winter and the highest was 20.5°C measured in the summer. The narrow range of seasonal temperatures in S 3 was apparently the result of underground springs in the upper reaches of the watershed. Discharge data from the five streams provided further evidence that S 3 was spring fed. Daily average discharge in S 3 was three times greater than that in the other streams (Table 2).

Total precipitation measured at the substation near all watersheds in 1993, 1994 and 1995 was 1,504, 1,272 and 1,478 mm respectively (Unpublished Data, Alabama Experiment Lower Coastal Plain Substation, Camden, AL). However, 41% of the rain

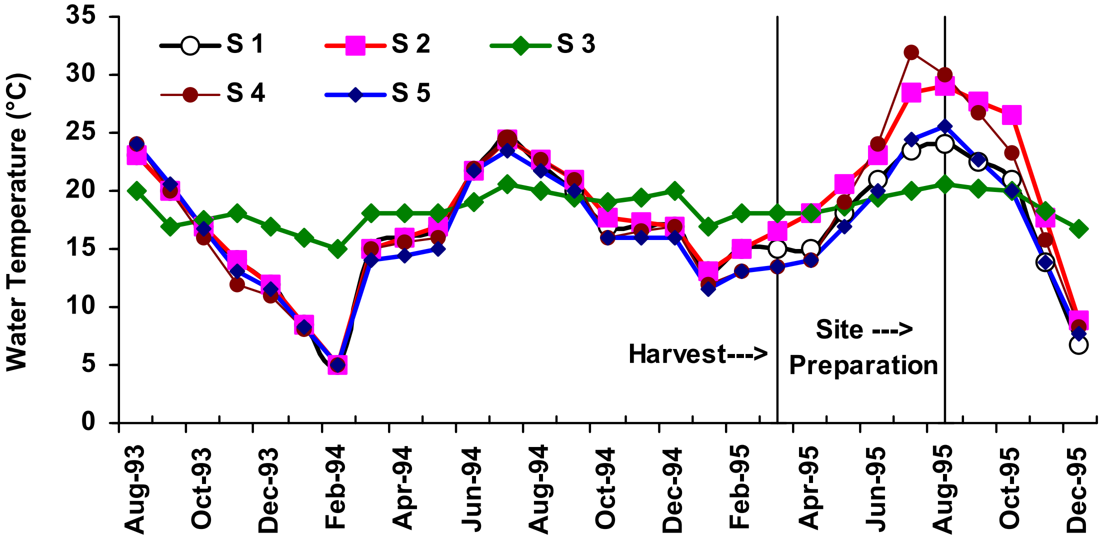

Figure 3. Water temperatures for the five streams (S1...S5) in Wilcox County, Alabama. Values were measured at the upper station in each stream on each date.

Table 2. Total precipitation and mean daily water discharge from five watersheds in Camden, Wilcox County, Alabama during 1995.

Watershed	Total Rainfall (mm)	Mean Daily Discharge (m^3)
1	1360	24.4
2	1327	31.7
3	1375	95.4
4	1229	21.4
5	1211	22.8

measured in 1995 was collected in the last three months of the year and included the effects of Hurricane Opal.

Water temperatures measured in S 1 were similar to those measured during the same period prior to disturbance. After harvest between March and August maximum temperatures in S 2 and S 4 with no SMZ were significantly higher ($p<0.05$) than values measured in S 1 (Figure 4). Temperature increases in S 2 were smaller than those occurring in S 4, probably because harvest on W 2 was not as complete as that on W 4. Mechanical harvest was impossible on the steep banks of S 2 therefore manual removal of the trees was required but not until late July 1995. Riparian trees on the steep banks of S 2 provided some shading to the stream. This data certainly reflected the importance of the SMZ in reducing temperature changes in streams of clearcut watersheds.

After harvest, water temperatures in S 5 with an SMZ was not modified significantly ($p>0.05$) from predisturbance conditions indicating that the riparian vegetation was sufficient to prevent temperature changes (Figure 5). The significant difference observed between S 1 and S 3 after harvest was probably due to the fact that S 3 is springfed and its temperature remained relatively constant year-around. The negative difference observed between S 3 and S 1 reflected the fact that temperatures in S 3 did not increase during the summer as they did in S 1. The shift in mean temperature in S 1 was from around 10° to 30°C, while changes in S 3 averaged only 17° to 19°C because of the spring influence.

When riparian vegetation is logged, water temperatures in streams usually increase during summer and may decline in winter (Graynoth 1979). In this experiment the

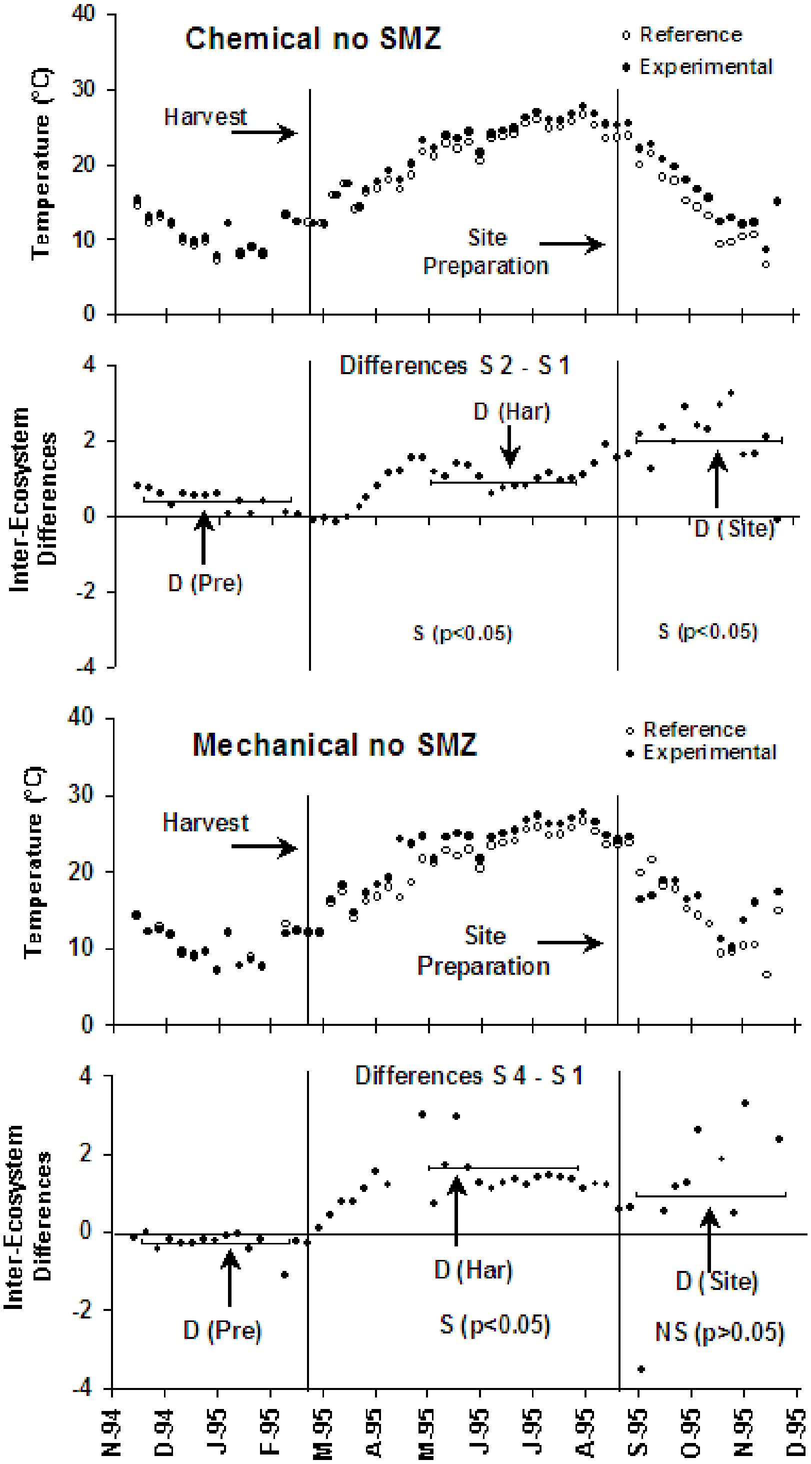

Figure 4. Water temperatures for the reference stream S 1 and S 2 and S 4 with no SMZ. The inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed differences are shown for the three phases of the study, pre-disturbance (D-Pre), post-harvest (D-Har) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation was analyzed against the pre-disturbance period.

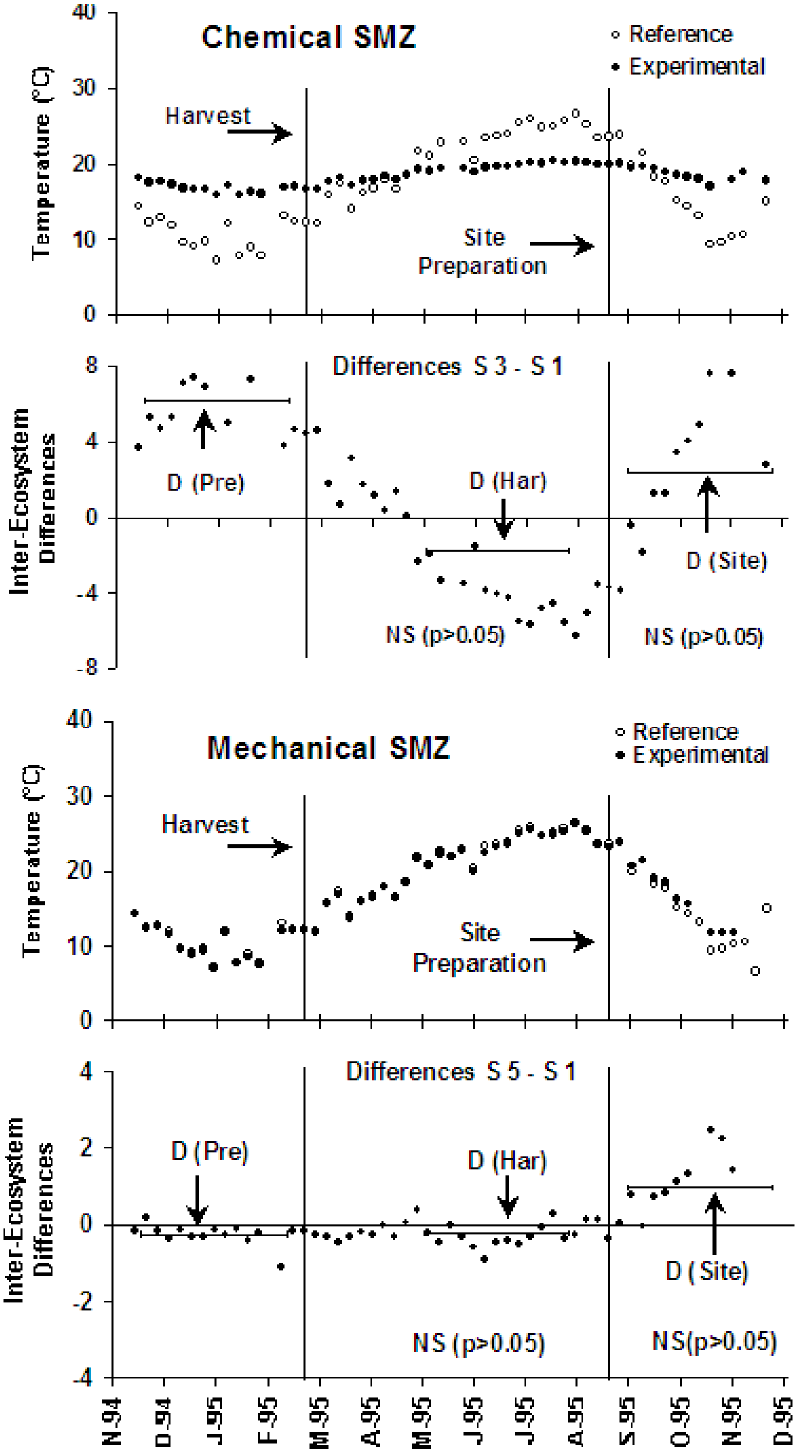

Figure 5. Water temperatures for the reference stream S 1 and S 3 and S 5 with an SMZ. The inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed differences are shown for the three phases of the study, pre-disturbance (D-Pre), post-harvest (D-Har) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation was analyzed against the pre-disturbance period.

most conspicuous effect was increased water temperatures observed during the summer because no sampling was conduced after December 1995. Similar temperature effects have been reported from studies conducted in other parts of the USA. A difference of 7°C in monthly maximum temperature between clearcut and reference streams was found in New England (Noel *et al.* 1986). Lee and Samuel (1976) observed a mean temperature increase exceeding 4°C but maximum increases exceeding as much as 9°C in a similar study in West Virginia. In a coastal stream in Oregon maximum monthly temperature was 7.8°C higher than those recorded before logging, while maximum temperatures observed after logging was 29.4°C compared to 13.8°C prior to the clearcut (Hansmann and Phinney, 1973). Also, from an Oregon stream, Brown and Krygier (1970) reported an increase of about 8°C after harvesting its small watershed.

After site preparation, water temperatures in the streams from the chemically treated watersheds W 2 and W 3 were significantly different from the reference only in S 2 (Figures 4 and 5). This difference was probably related to the treatment effects of the herbicide on the riparian vegetation grown following harvest. However, in S 3 water temperatures varied little from pre-disturbance periods because of the spring influence. After mechanical site preparation stream temperatures were not significantly different in S 4 compared to S 1. The movement of debris (windrowing) during mechanical site preparation on W 4 did not affect the new growth of riparian vegetation. Following site preparation on W 4 dense growths of weeds and small shrubs remained on the banks all along the channel of S 4. Shade provided by this new growth of shrubs apparently reduced temperature differences between S 4 and S 1 (Figure 4). In S 5 the SMZ apparently was wide enough to prevent stream temperatures from increasing significantly during the fall. In addition, deciduous hardwoods dominated riparian vegetation along S 5 while 56% of trees in W 1 were pines (Marshall 1999). The loss of leaves as fall approached probably allowed more solar radiation to reach S 5 causing higher temperatures than those measured in S 1 but not statistically different.

Burton and Likens (1973) found that water temperatures were constant in a 625-m stream section prior to harvest; but after a clearcut conditions were altered producing a stream section with zones of rapid cooling and warming water. Similar situations were observed during this study when the loss of canopy cover influenced water temperatures in the streams. These changes were more conspicuous within the clearcut areas than downstream. For example in S 4 temperatures taken 300-m downstream from the clearcut during mid-summer were 7°C cooler than that measured inside the clearcut area. Burton and Likens (1973) also suggested that small headwater streams have the capacity to recover quickly and return to normal temperature. During this study only small non-significant increases in water temperature were observed below the clearcut area in all streams. Moreover, because of the natural aspect of these small watersheds, the position of the sun affected all watersheds in a similar manner. Temperature differences are indeed affected by the angle of the sun and the direction toward which a slope faces, but these factors could not be addressed during this study.

Dissolved oxygen (DO) prior to disturbance was similar in all streams ranging from 6.2 ppm in S 4 to 13.6 ppm in S 1. Lower DO values were recorded during low stream flow periods in the summer. After harvest DO ranged from a low of 5.8 ppm in S 5 to a high of 9.6 ppm in S 4. DO was significantly modified ($p<0.05$) in S 5 with an SMZ after harvest. Low flow conditions, lower periphyton biomass and higher fine benthic organic matter present could be responsible in part of this measurement. No significant differences (p>0.05) in dissolved oxygen were observed among all streams after site preparation.

C. Herbicide Fate

Aerial application of the herbicide resulted in little Imazapyr detected in S 2 and S 3 on the day of application. As a result of direct flight over S 2, the 24-hr average Imazapyr concentration measured the day of treatment was 0.127 mg/L in S 2 and essentially almost zero in S 3 (Figure 6). The minute concentrations of Imazapyr detected in S 3 on that day strongly suggested the mitigating effects of the SMZ. This mitigating effect remained evident in S 3 during normal rain events over the next several weeks. However, normal rain events recorded during this period did result in runoff of Imazapyr to S 2. Four weeks following application concentrations of Imazapyr in S 2 had declined to zero.

Measurable levels of Imazapyr were not detected in water samples until the fifth week after treatment in S 3 (0.028 mg/L) and probably occurred then because of the increased surface runoff of water caused by heavy rains following Hurricane Opal on October 3-4, 1995. The heavy rains from Hurricane Opal also resulted in another peak of Imazapyr in S 2 (0.045 mg/L). Following Hurricane Opal, further surface runoff of Imazapyr into S 2 and S 3 was essentially non-existent. In fact, no herbicide was detected in water samples from S 2 or S 3 two months after the treatment. Between 96 and 99% of the total Imazapyr offsite movement to S 2 and S 3 occurred during Hurricane Opal.

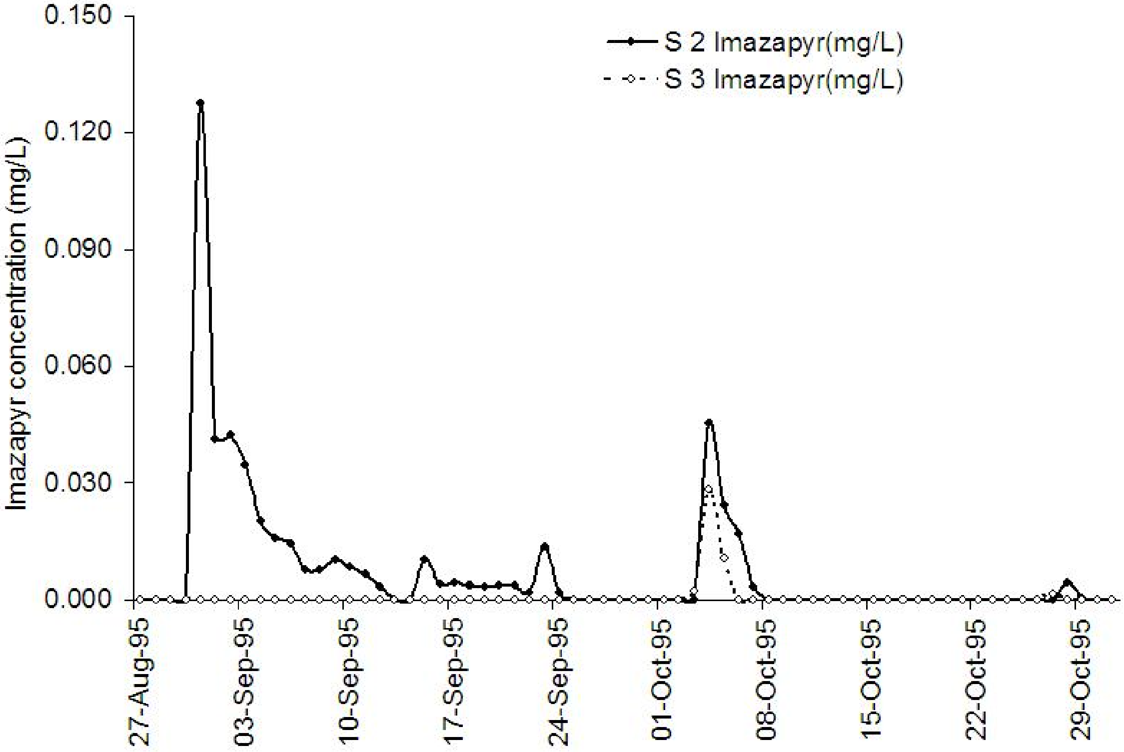

Figure 6. Daily average concentrations of imazapyr (mg/L) calculated over 24-hr periods, measured in S 2 and S 3 after chemical site preparation in Camden, Alabama, 1995.

Imazapyr was found to be lethal to fish and aquatic invertebrates only in concentrations greater than 100 mg/L (SERA 2004). The highest concentrations measured in this study were a fraction of those considered lethal to aquatic biota.

No analyses were conducted for detection of glyphosate, thus it is not known how much glyphosate was in streamflow during and after the application. Glyphosate residues are not directly amenable to gas chromatography or most detection systems that can be used for HPLC (Personal communication, Dr. Jerry Michael, USFS, 1998). In addition, methods for analyzing glyphosate like the EPA method 547 are time consuming and specialized equipment is required. Besides, glyphosate is strongly adsorbed to soil, remaining in the upper soil layers and has a low propensity for leaching (Gerritse *et al.*

1996; Morillo *et al.* 2000). Finally, considering the proportions of the herbicides applied in this study, if some glyphosate reached the experimental streams it is likely that it was in concentrations below the levels harmful to aquatic fauna (Henry *et al.* 1994).

D. Nitrogen and Phosphorous

Nutrient content in the watershed soil usually determines the concentrations in the stream flowing through that watershed. Nutrient analyses of soils from the Camden watersheds before clearcut indicated concentrations of N, P and K typical for the Coastal Plain province (Personal communication, D. Marshall, 1998). Stream measurements of total nitrate-nitrogen (NO_3-N) and total phosphate-phosphorus (PO_4-P) taken before harvest were variable but were relatively high compared to other small streams. Total NO_3-N concentration was 1.5 mg/L, or higher in 29% of the samples and mean values in S 1 and S2 were an order of magnitude higher than in S3, S4 and S5 (Table 3).

Higher values of NO_3-N in S 1 and S 2 may have been related to runoff from cropland and pastures located on the headwaters of these watersheds. As the summer months approached dense vegetation in W 1 apparently reduced nitrogen, accounting in

Table 3. Weekly mean total nitrate-nitrogen and total phosphate-phosphorous (mg/L) in study streams in Camden, AL between October 1994 and November 1995.

Stream / treatment	Pre Disturbance		Post Harvest		Post Site Preparation	
	N	**P**	**N**	**P**	**N**	**P**
S1-Undisturbed Reference	0.508	0.03	0.096	0.00	0.003	0.00
S2-NO SMZ, Chemical	0.577	0.02	0.232	0.01	0.318	0.00
S3-SMZ, Chemical	0.017	0.02	0.090	0.00	0.021	0.01
S4-NO SMZ, Mechanical	0.013	0.68	0.077	0.10	0.036	0.03
S5-SMZ, Mechanical	0.003	0.00	0.179	0.04	0.092	0.12

part, for its decline in S 1 to about half of fall-winter values. NO_3-N in S 1 declined throughout this study.

After harvest, NO_3-N concentration in S 2 declined to about one third of pre-disturbance values. However, in S 3 and S 4 nitrogen concentrations increased about five times and in S 5 the increase was almost sixty times that measured prior to disturbance. The nitrogen decrease in S 2 (and S1) suggested depletion by vegetation in each watershed as values approached those measured in the other streams. In S 2 the NO_3-N decrease was also probably related to the uptake by the riparian vegetation left along the steep banks of the streams that were not harvested until late July 1995. In addition, considerable growth of shrubs and vines developed by the time all trees were harvested in W 2. This vegetation apparently used nitrogen before it could reach S 2, as in the undisturbed stream. Increases in NO_3-N in S 2 at the end of the study probably reflected the lack of vegetation following chemical treatment. Nitrogen increases in S 3, S 4 and S 5 after harvest probably resulted from the lack of vegetation in those watersheds to take it up.

After site preparation the SMZ may have played a filtering role for NO_3-N concentrations in S3 where levels declined almost 80% from post harvest values. Nitrate-nitrogen in S 3 following site preparation was similar to levels measured prior to disturbance. Compared to post-harvest values, NO_3-N concentrations in both S 4 and S 5 decreased 60% following mechanical treatment. However, even with no SMZ, S 4 had vegetation growing along the stream banks that mechanical site preparation did not disturb. Among all streams, nitrogen concentrations in S 4 after site preparation were the closest to pre-disturbance values. Vegetation in the SMZ along S 5 probably played a role in the use of nitrogen before it reached this stream. Nevertheless, nitrate-nitrogen in S 5 following mechanical site preparation was three orders of magnitude higher than pre-disturbance values. Measurements taken at the end of the experiment in December 1995 revealed NO_3-N values in S 1 (.023 mg/L) and S 3 (0.657 mg/L) comparable to values reported in a study by Haefner and Wallace (1981). Water samples from S 4 and S 5 had lower levels of nitrogen than those in S 1 and S 3, but S 2 had some of the highest measurements observed during this study with an average of 4.9 mg/L in December 1995.

Total PO_4-P concentrations before harvest were similar in streams S 1, S 2, S 3 and S 5 with values of 0.03 mg/L or smaller (Table 3). However, concentrations in S 4 averaged 0.68 mg/L. PO_4-P concentrations remained low through the study at all streams and declined in S 4 to similar levels. In addition, an unexplained slight increase in PO_4-P concentration was observed in S 5 during the study. However, these changes seem to have been not related to the watershed treatments. Water analyses of samples collected from the Camden streams sites 2 years after site preparation revealed NO_3-N and PO_4-P in concentrations <1 mg/L (Unpublished Data, AU Rivers and Reservoirs Laboratory). These values were comparable to those typically found in lower order streams (Swank and Douglas 1975, Cuffney *et al.* 1984).

Greater nutrient concentrations in streams have been found in different parts of the USA up to 3 years after site preparation when compared to undisturbed reference sites; even when the clearcuts left an SMZ (Martin and Pierce 1980, Feller and Kimmins 1984, Blackburn and Wood 1990). However, a study from the lower Coastal Plain of

Georgia found no significant differences of NO_3-N in groundwater regardless of the forest management technique used (Hubbard and Lowrance 1997).

E. Streambed Substrate

Before harvest, the substrate in all streams was similar at all stations with gravel and sand making up 71% to 86% of the streambed (Figure 7). Gravel ranged from a low of 33% in S 2 to a high of 52% in S1. Sand was lowest in S5 and highest in S 3. Pebbles composed about 14% at all sites except S 2 where it was 28%. Cobble and silt provided no more than 10 % of the total substrate in all streams except in S 3 where silt was 15%.

After harvest gravel and sand still comprised the greater percentage (72-98%) of substrate material at all streams including S 1; but the proportion of gravel to sand was slightly higher compared to pre-disturbance conditions except in S 3 (Figure 7). Pebbles were reduced in all streams to a small percentage and silt increased reaching a high of 20% in S 4. Percentage of sand increased in S 3 after harvest going from a 29% to a 51%. Field observations revealed the existence of several gullies inside the SMZ facilitating the movement of sediments into S 3. In addition, Marshall (1999) found significantly greater erosion after harvest in all clearcut watersheds compared to pre-disturbance conditions. Substrate composition after harvest at stations 300-m below the clearcuts showed a seven percent increase in sand in treatments without an SMZ but no change was observed in the treatments with an SMZ.

During the fall of 1995 stream substrate was more evenly composed in all streams with evident presence of sand and cobble (Figure 7). The shift in substrate composition in the streams during this period may have not been related to site preparation treatments because excess sand and cobble was also observed in the reference stream with the undisturbed watershed. A possible explanation for this incidence is the passing of Hurricane Opal in October 1995. Opal deposited 210 mm of rain in a 48-h period and resulted in heavy surface run-off in the area. Stream channels after Opal had extra sand and/or silt, noticeable while walking along the stream banks.

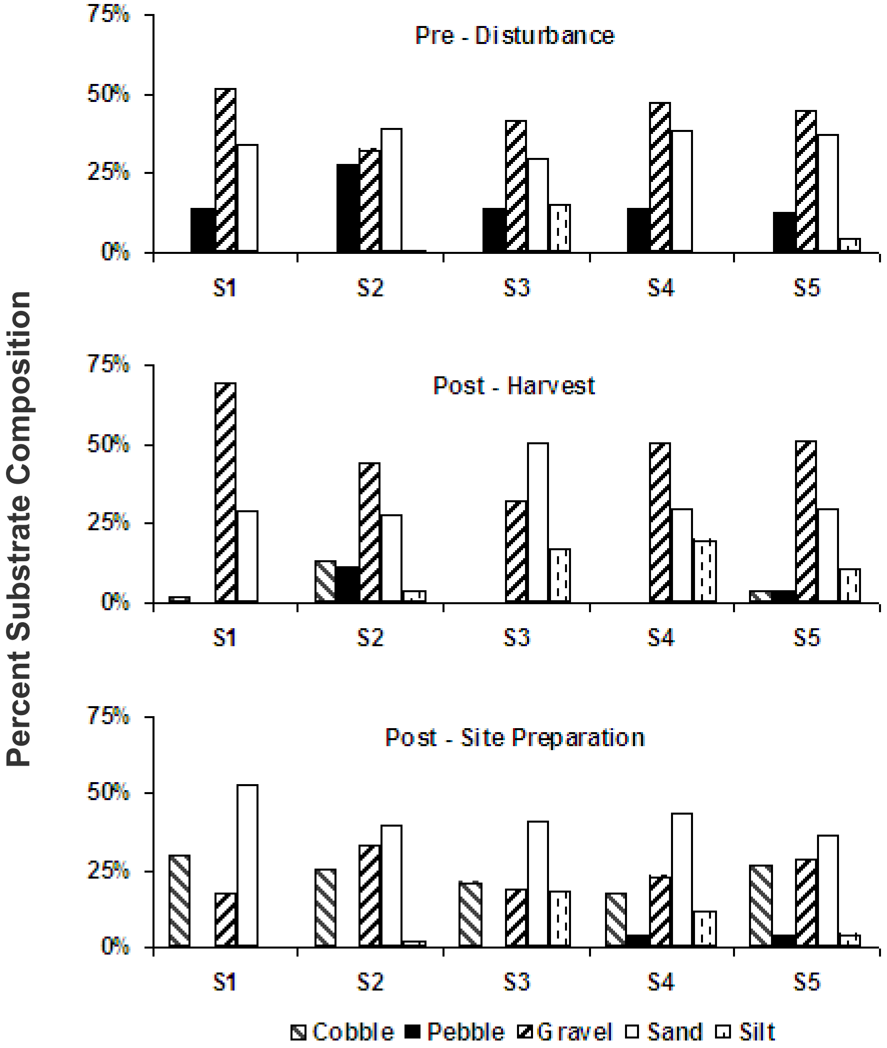

Figure 7. Mean substrate composition from five streams at Camden, Alabama during 1995 prior to disturbance, after timber harvest and after site preparation.

Compared to predisturbance conditions, the percentage of silt also increased after site preparation at stations below the clearcuts but the chemically prepared sites showed smaller increases in silt than those mechanically prepared. In general substrate composition below clearcuts did not change markedly during 1995. Thus, the dominance of gravel indicated good substrate for periphyton and macroinvertebrate communities. Sediment movement can be dramatic in small Coastal Plain streams and heavy rains following site preparation resulted in large amounts of sediments moved, thus uncovering more cobble in stream channels. No statistical analysis to support changes in substrate composition related to the logging operation were conducted due to the lack of seasonal sampling before clearcut.

F. Benthic Organic Matter

Total benthic organic matter (BOM) prior to harvest was similar in all streams with fine benthic organic matter (FBOM) comprising 86 to 96% of the total, large benthic organic matter (LBOM) comprised 4 to 13% and woody debris (WD) provided only 3% or less (Figure 8). Similar findings were reported from small streams in North Carolina (Golladay *et al.* 1989) although they also found sites where LBOM was dominant.

Mean total organic matter, measured in 1995 before harvest, as ash free dry mass (AFDM) was variable but within ranges found in streams of similar order. For instance, of the five Camden streams, S 2 had the smaller amount of organic matter at 1,329 g AFDM/m^2 (Table 4). These values were similar to that reported in Carpenter Branch, North Carolina of 1,135 g AFDM/m^2 by Golladay *et al.* (1989). Total BOM in S 4 was 1,832 g/m^2 essentially the same as the 1,831 g/m^2 found in a comparable stream at Sawmill Branch in North Carolina; among all sites the highest BOM value of 2,759 g/m^2

recorded in S 3 (Table 4) was still within the range identified by Golladay *et al.* (1989) for small streams. The higher BOM found in S 3 probably reflected the influence of springs that maintained more constant water levels in this stream.

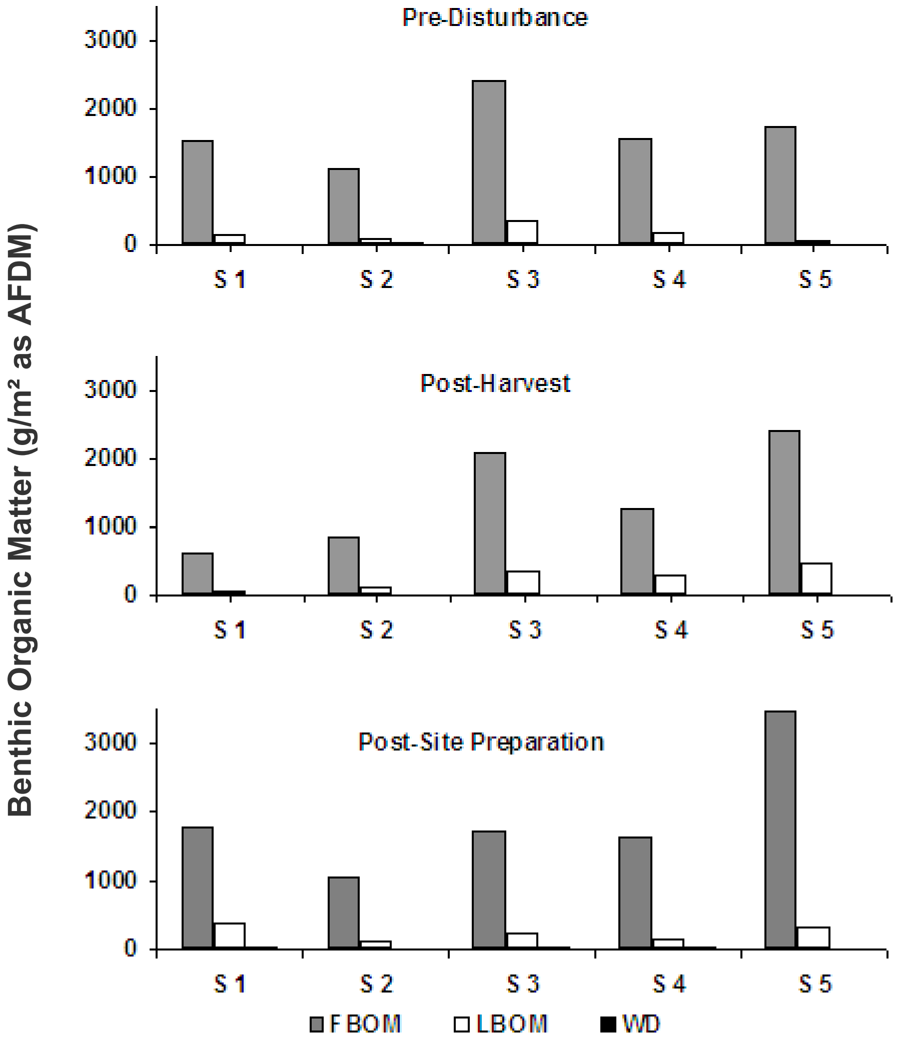

Figure 8. Benthic organic matter composition (as g/m² of AFDM) in five streams in Camden, Alabama before timber harvest (top), after harvest (middle) and after site preparation (bottom) during 1995 (FBOM = Fine Benthic Organic Matter, LBOM = Large Benthic Organic Matter, WD = Woody Debris).

After harvest BOM decreased in all streams that received a clearcut, except for S 5 (Table 4). BOM decreased more in S 2 and S 4 (streams left with no SMZ) than in S 3 and S 5 with an SMZ. BOM actually increased in S 5 following the clearcut harvest. BOM decrease was also measured from the samples collected at S 1. Therefore, BOM decreases may have been related to the time of the year when this sampling occurred (Spring to mid-Summer). In addition, lack of rains during this period may have also influenced low BOM measurements. BOM increases in S 5 may have been related to the fact that the dominance of deciduous trees over pines was greater in W 5 than in the other watersheds (Marshall 1999).

Also, the reach of S 5 sampled for BOM was a long low gradient section and organic matter may have had greater accumulation in this stream channel than in the other experimental streams. The decline in BOM in S 3 following harvest was probably related to the clearcut. There was no good explanation for the small decrease in BOM in S 4 because all of the trees 4 inches in diameter, or greater, were removed to the edge of the stream bank in this watershed.

Table 4. Mean benthic organic matter (g AFDM/m^2) in the five streams in Camden, AL, during 1995 prior to disturbance, after timber harvest and after site preparation within the clearcut area.

Station	Treatment	Pre Disturbance	Post Harvest	Post Site Preparation
S 1	Undisturbed Reference	1,687	688	2,172
S 2	NO SMZ, Chemical	1,329	972	1,185
S 3	SMZ, Chemical	2,759	2,456	1,977
S 4	NO SMZ, Mechanical	1,832	1,589	1,779
S 5	SMZ, Mechanical	1,440	2,874	3,788

Following site preparation, BOM increased in all streams from that measured during the post harvest period except at S 3 (Table 4). BOM increases were, in large part, natural occurrences since sampling took place during autumn months. In addition, high BOM after site preparation could be related to heavy rains (e.g. Hurricane Opal) following dry periods that flushed more organic matter into the stream channels. The dramatic changes in BOM in S 1 may have been a natural variation in this undisturbed watershed. BOM declines in S 3 after site preparation could be related to less organic matter input due to the clearcut in W 3 plus the higher presence of evergreen magnolia trees and the SMZ. Conversely, the herbicide applied to W 2 and the mechanical preparation on W 4 and W 5 apparently resulted in a great deal of dead vegetation on these watersheds. These activities contributed to more BOM runoff into the streams.

G. Periphyton Chlorophyll

Except for S 3, chlorophyll *a* values in all streams were similar before harvest with mean values ranging from 0.3 to 1.7-mg/m^2 (Table 5). Chlorophyll *a* values in S 3 averaged over four times higher than that in the other streams perhaps because of the spring-influenced more stable flow and temperatures year around. Low values of chlorophyll *a* per m^2 are common in low order streams with a dense canopy because little solar radiation reaches the stream bottom (Lowe *et al.* 1986). For example, DeNicola *et al.* (1992) found only 0.01 to 0.33 mg/m^2 in small streams in eastern Nebraska, and Mulholland and Rosemond (1992) reported 0.07 to 0.61 mg/m^2 in deciduous-forest streams in eastern Tennessee.

Periphyton communities responded rapidly to changes in water temperature in these small, low gradient streams. During a two-week period in February 1995 prior to harvest (Figure 9, 10, 11, 12) a warming spell occurred with maximum air temperatures reaching 21°C. Historic winter maximum temperatures in the Camden area average 8°C and minimum of 2°C. Soil temperatures reached highs of 17°C and lows of 13°C. Water temperatures during this period reached 17°C. The reduced canopy from leaf fall plus sunny days produced water temperatures that apparently contributed to unusually high chlorophyll *a* values in all streams.

Table 5. Minimum, maximum and mean chlorophyll *a* (mg/m²) before disturbance (n=42) and after timber harvest (n=12), at nine stations in five streams in Camden, Alabama during 1993-1995. *Value estimated from one sampling date (n=3) because of lack of flow during other sampling dates after harvest. a = within clearcut, b=below clearcut.

	Pre Disturbance (Aug 1993 – Feb 1995)			Post Harvest (Mar 1995 – Aug 1995)		
	Min	Max	Mean	Min	Max	Mean
S 1	0.0	2.8	1.2	3.3*	3.3*	3.3*
S 2a	0.2	8.1	1.7	4.1	28.0	16.3
S 2b	0.5	4.2	1.6	2.1	12.2	8.7
S 3a	1.2	14.5	7.4	7.5	64.4	37.1
S 3b	3.0	13.2	7.5	9.1	82.2	38.0
S 4a	0.0	3.6	0.9	0.4	99.6	44.8
S 4b	0.0	4.6	0.9	0.0	31.4	14.7
S 5a	0.0	0.9	0.3	0.2	17.8	10.6
S 5b	0.2	4.0	1.2	1.9	19.6	11.9

After harvest, mean chlorophyll *a* measurements from the two sites with no SMZ, S 2 and S 4, were significantly higher ($P<0.05$) than that measured in the reference stream (Figures 9, 11 and 13). These increases in chlorophyll *a* in S 2 and S 4 apparently resulted from the reduced canopy cover and subsequent increased sunlight reaching the stream bottom, and/or the availability of more nutrients. For example, nitrogen and phosphorous values were relatively high in S 2 and S 4; S 2 registered the higher NO_3-N

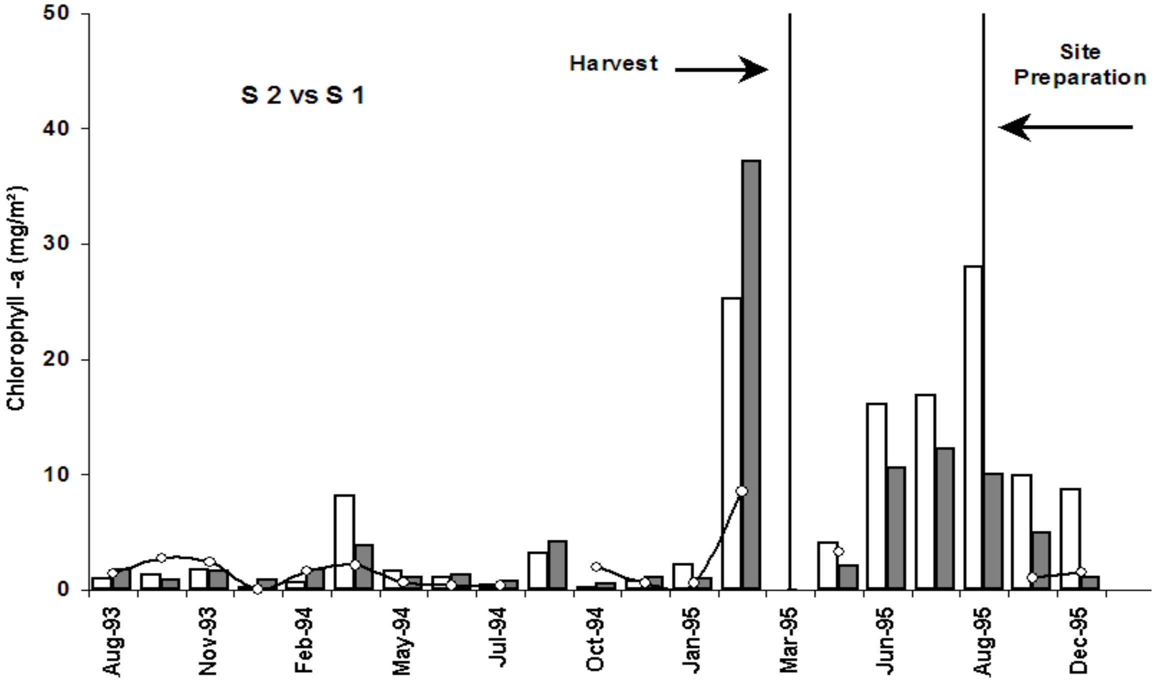

Figure 9. Chlorophyll *a* (mg/m²) concentrations in S 2 (No SMZ) inside (clear bar) and below (dark bar) the clearcut and in S 1 (line) in Camden, Alabama from August 1993 to December 1995.

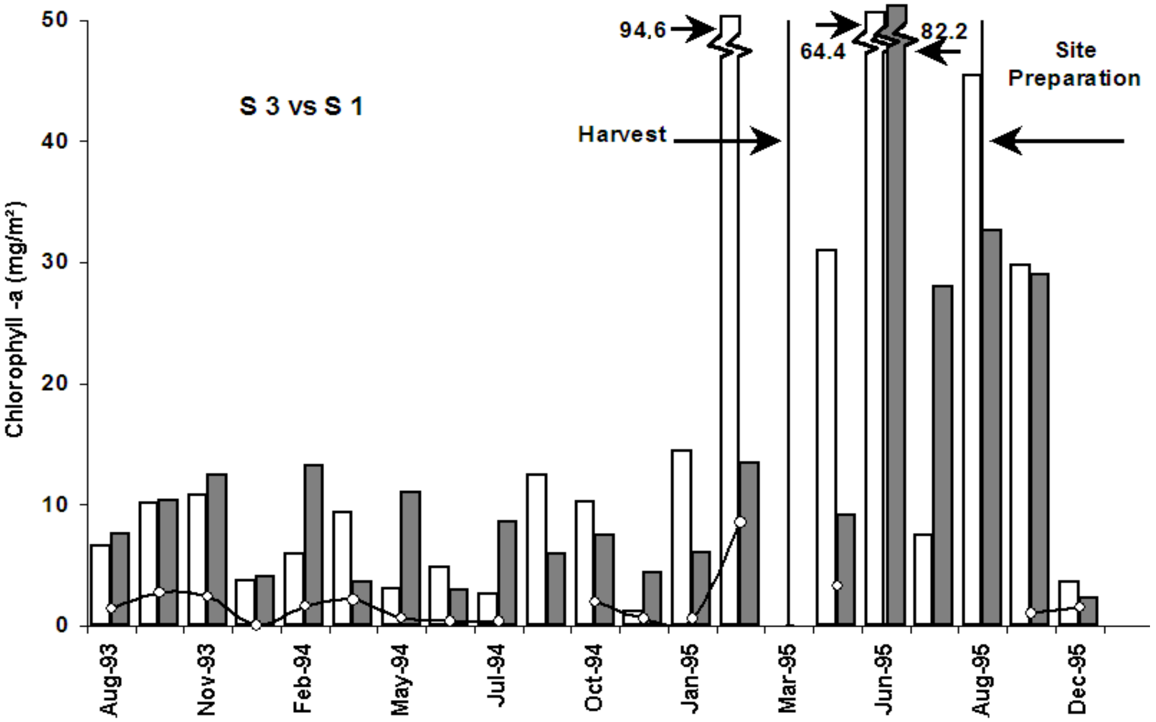

Figure 10. Chlorophyll *a* (mg/m²) concentrations in S 3 (SMZ) inside (clear bar) and below (dark bar) the clearcut and in S 1 (line) in Camden, Alabama from August 1993 to December 1995.

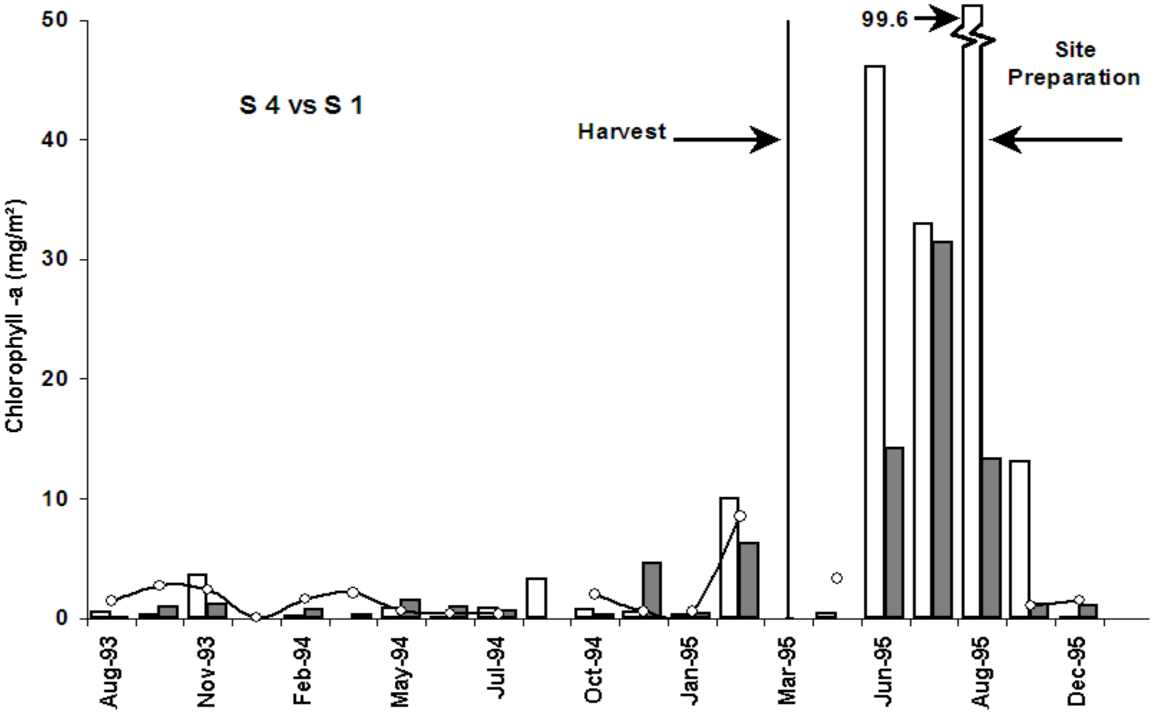

Figure 11. Chlorophyll *a* (mg/m²) concentrations in S 4 (No SMZ) inside (clear bar) and below (dark bar) the clearcut and in S 1 (line) in Camden, Alabama from August 1993 to December 1995.

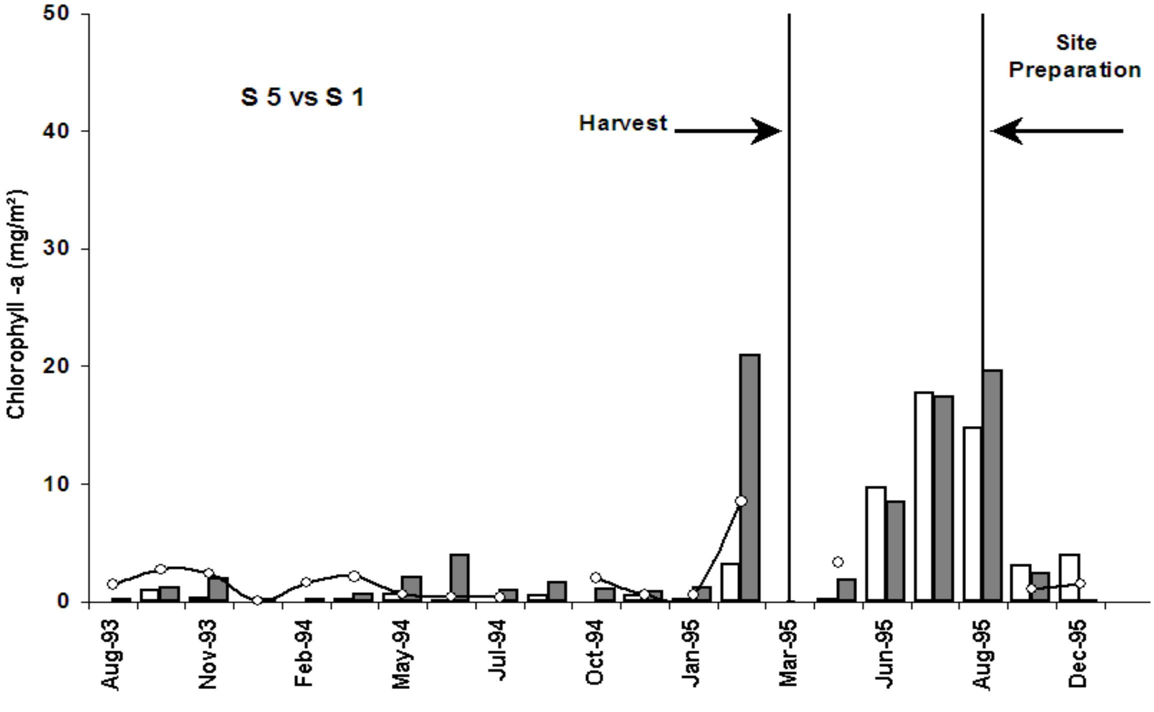

Figure 12. Chlorophyll *a* (mg/m²) concentrations in S 3 (SMZ) inside (clear bar) and below (dark bar) the clearcut and in S 1 (line) in Camden, Alabama from August 1993 to December 1995.

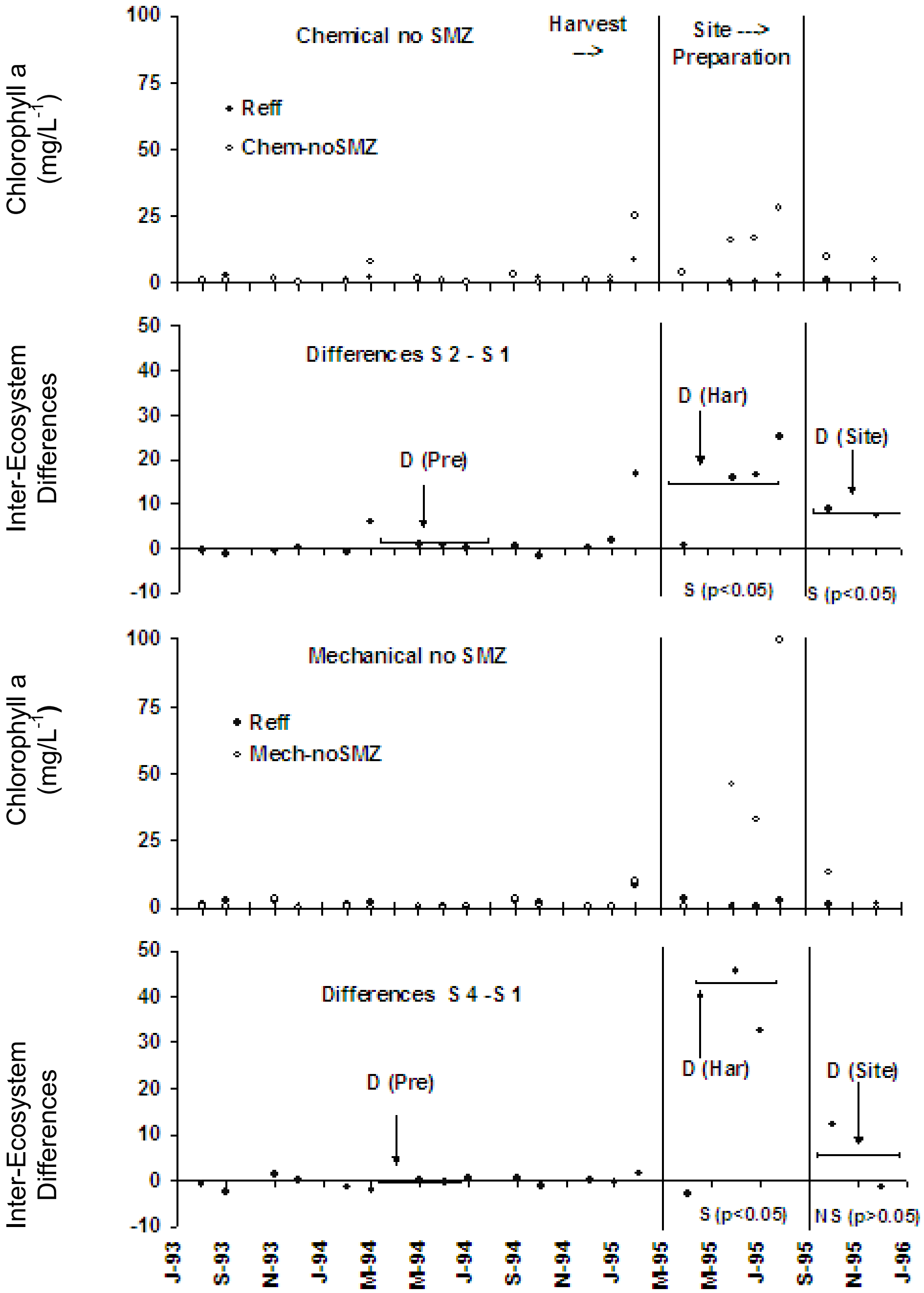

Figure 13. Mean chlorophyll *a* measured in a reference stream S 1 and two experimental streams S 2 and S 4 with no SMZ in Camden, Alabama. The inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed difference are shown for the three phases of the study pre-disturbance (D-Pre), post-harvest (D-Pre) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation was analyzed against the pre-disturbance period.

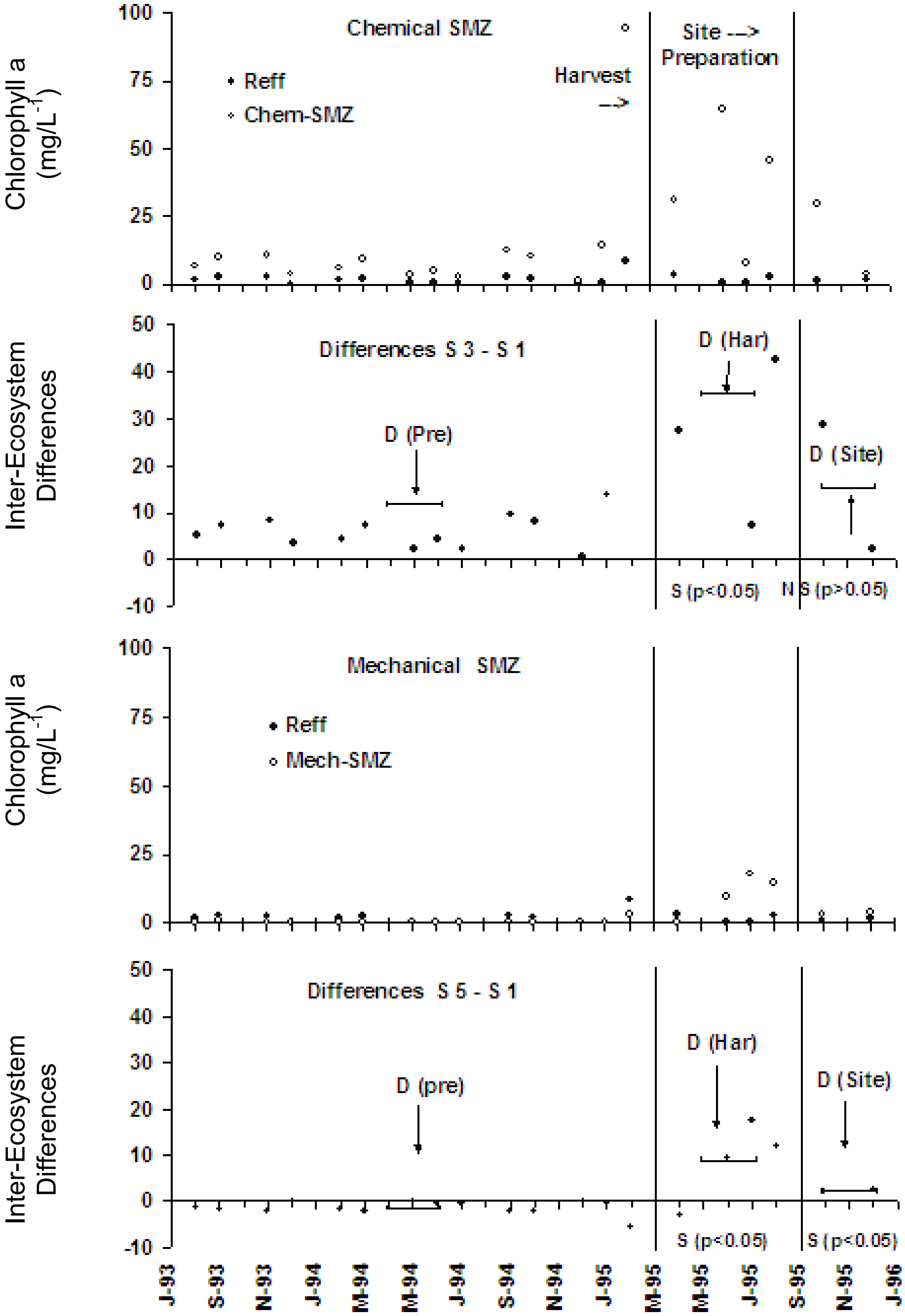

Figure 14. Mean chlorophyll *a* measured in a reference stream S 1 and two experimental streams S 3 and S 5 with an SMZ in Camden, Alabama. The inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed difference are shown for the three phases of the study pre-disturbance (D-Pre), post-harvest (D-Pre) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation was analyzed against the pre-disturbance period.

concentration and S 4 registered the higher PO4-P values during this period of time. Periphyton biomass values from S 2 within the clearcut were five times higher than those measured in S 1, while values from S4 were 13 times higher (Table 5).

The largest amount of chlorophyll *a*, about 100 mg/m² was measured at S 4a (no SMZ) in August 1995. By this time large masses of filamentous algae were observed covering almost the entire channel of S 4. Following harvest the chlorophyll *a* measurements in both S 3 and S 5 were significantly higher ($P<0.05$) than that measured in the reference stream S 1 (Figure 10, 12 and 14). Chlorophyll *a* increases in the stream reaches downstream from the clearcuts were smaller than those occurring within the clearcut, but still ranged from five to almost twenty times higher than measurements recorded before harvest.

These increases in chlorophyll *a* after harvest were higher statistically significant ($P<0.05$) from values recorded prior to harvest (Figure 14). Chlorophyll *a* values at S 4b were about one eighth that of measurements at S 4a indicating that the dense canopy reduced light to the stream bottom (Table 5). Increases of chlorophyll *a* after timber harvest have been reported previously but usually of smaller magnitude than those measured in this study. For example, Murphy and Hall (1981) reported greater chlorophyll *a* accumulation (up to 36.6 mg/m²) in 5-17 year old clearcut sections of streams in Oregon, compared to old growth forested sections. In Oregon, Gregory (1980) reported stream reaches inside clearcut areas had about twice the annual primary productivity of undisturbed streams.

Periphyton cell densities up to six times higher were found in clearcuts compared to undisturbed references in 1st and 2nd order streams in New England (Noel *et al.* 1986).

Lowe *et al.* (1986) found chlorophyll *a* concentrations up to 20 times higher in 2nd order streams from timber-harvested watersheds in North Carolina compared to reference sites. Those studies were conducted more than 2 years after harvest, but the difference in primary productivity was associated with the clearcut disturbance.

Algal production is by nature highly variable in small streams; however, disturbance effects in streams often cause changes in algal biomass. The increases in chlorophyll *a* observed in all the experimental streams in this study were undoubtedly a consequence of the clearcut disturbance.

After harvest, the reduced canopy cover allowed more sunlight to reach the stream channels and the increased water temperatures had a positive effect on the periphyton growth. Chlorophyll *a* values from dense periphyton communities is usually correlated with canopy cover (De Nicola *et al.* 1992) and is, in general, greater in streams with an open canopy than in streams with a closed canopy (Lowe *et al.* 1986, Feminella *et al.* 1989, Corkum 1996). In addition, temperature is well known as a major controlling physical factor for organisms and is very important in determining both the community structure and the temporal succession of organisms (Hynes 1972). The February 1995 warming trend was an example of the rapid positive effect of temperature on periphyton communities.

The availability of nutrients has often been pinpointed as a limiting factor for periphyton production in small headwater ecosystems (Stockner and Shortreed 1978, Peterson *et al.* 1983, Grimm and Fisher 1986, Hart and Robinson 1990). Increased nutrients such as potassium and nitrate-nitrogen through runoff following clearcuts were documented by Lynch *et al.* (1985) in central Pennsylvania. Nutrient concentrations above the typical range for these elements were measured at all streams in this study, therefore augmenting the possibilities for increases in periphyton biomass.

Mean chlorophyll *a* measured in the reference stream (S 1) during the autumn of 1993, 1994 and 1995 showed no differences between seasons. Following site preparation in the fall of 1995, within the treated watersheds, chlorophyll *a* values were three to eighteen times higher than those measured during similar time periods before disturbance (Table 6). However, RIA detected significant differences only at stations S 2a and S 5a where differences in autumn values of mean chlorophyll *a*/m² before and after site preparation were larger.

Table 6. Mean chlorophyll *a* (mg/m²) before site preparation (11/93, 12/93,10/94, 12/94, n=12) and after site preparation (10/95, 12/95, n=6) and percentage increase from stage to stage for the reference stream and the sites within each clearcut watershed.

Station	Treatment	Pre Disturbance	Post Site Preparation	Percentage Increase
S 1c	Undisturbed Reference	1.3	1.3	0
S 2a	NO SMZ, Chemical	0.8	9.3	1063
S 3a	SMZ, Chemical	6.5	16.7	157
S 4a	NO SMZ, Mechanical	1.2	6.6	450
S 5a	SMZ, Mechanical	0.2	3.6	1700

Changes in periphyton occur naturally with seasons in temperate latitudes increasing in summer and decreasing during fall-winter (Rosemond, 1994; Rosemond, *et al.* 2000). Site preparation usually takes place in late summer in the Southeastern USA, hence the effects of this type of disturbance on stream communities has to be separated from natural seasonal changes. Based on the chlorophyll *a* data from autumn 1994 and 1995 (Figures 9, 10, 11, 12) periphyton communities apparently died back in all streams during the fall of 1994. However, mean chlorophyll *a* values in 1995 in S 2 and S 3 remained higher than those measured in S 4 and S 5. The herbicide mixture apparently had no detrimental effect on periphyton communities during this research. In addition, the stream with an SMZ had smaller decreases in chlorophyll *a* measurements than that without an SMZ. Percentage increase of chlorophyll *a* suggested that chemical treatment created less disturbance than mechanical site preparation, and that the SMZ mitigated the disturbance (Table 6).

Mechanical site preparation apparently had the greater impact on periphyton communities but the treatment with an SMZ had greater change than the one without an SMZ. Evidently, the SMZ width was not adequate to prevent increases in periphyton biomass. In a study testing different SMZ widths, Davies and Nelson (1994) found that periphyton significantly increased only in SMZ smaller than 30 m. The SMZ in this study were only ~11-m wide.

H. Macroinvertebrate Communities

A total of 178 taxa were identified from all streams during this study (Appendix I). Aquatic insects in the order Diptera, mostly Chironomidae (midges), comprised 56% of the total fauna. Mayflies in the order Ephemeroptera comprised 11% of the fauna, and the remaining insect orders each had less than 10%. Miscellaneous other aquatic invertebrates included mostly amphipods, copepods, crayfish, water mites, nematodes, and turbellarians.

For the eight dates with detailed identification, the mean density for each site appears in Table 7. These data cover predisturbance, post harvest and post site preparation time periods. Mean numbers for the reference stream S 1 represent fewer dates because the stream was dry in September 1994, prior to harvest, and between May and

September 1995 during the post harvest period. Dipterans in Table 7 were mostly taxa in the family Chironomidae. More sensitive taxa in the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders were well represented at all stations.

Table 7. Major insect orders and mean number of macroinvertebrates collected from core samples at sites in Camden, Alabama from August 1993 to December 1995.

	Stations								
Order	1 C	2 A	2 B	3 A	3 B	4 A	4 B	5 A	5 B
Aquatic Insects									
Coleoptera	52	379	324	52	151	470	131	88	83
Diptera	646	3,624	3,715	359	344	2,241	1,039	1,159	1,364
Ephemeroptera	53	486	432	145	134	579	300	324	411
Megaloptera	0	2	0	1	0	0	0	0	0
Odonata	1	9	12	4	1	3	3	5	4
Plecoptera	257	100	191	16	78	106	52	40	86
Trichoptera	37	149	95	131	180	127	173	71	169
Other Aquatic Invertebrates									
Gastropoda	0	13	39	48	43	56	48	1	2
Oligochaeta	183	225	117	162	122	253	128	55	175
Pelecypoda	2	1	1	1	0	0	0	1	0
Miscellaneous	160	881	1,029	60	113	294	219	64	198
Total	1,410	5,876	5,968	982	1,173	4,142	2,108	1,813	2,496

1. Macroinvertebrate Density

Mean total macroinvertebrate density was determined for all seventeen dates during the study from both pool and riffle habitats combined (Figure 15 through 18). During the pre-disturbance period, pool inhabitants among all streams comprised 22 to 40% of the total macroinvertebrate density, while riffle inhabitants comprised 60 to 78%.

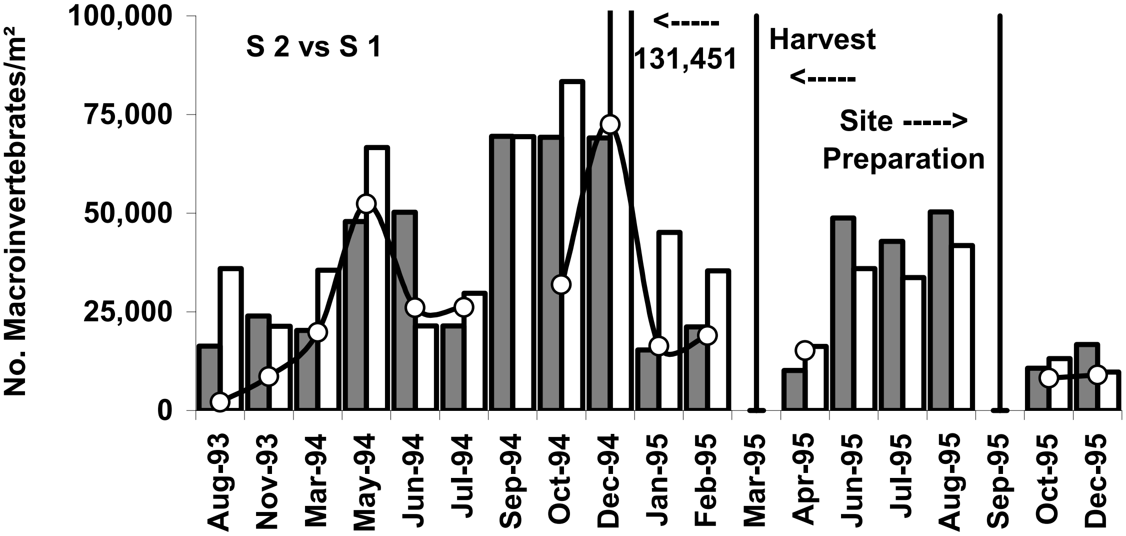

Figure 15. Mean total macroinvertebrate density (No./ m²) in S 2 – no SMZ and Chemically Site Prepared - inside (dark bar) and below (white bar) the clearcut and in the Reference Stream (line) in Camden, Alabama from August 1993 to December 1995.

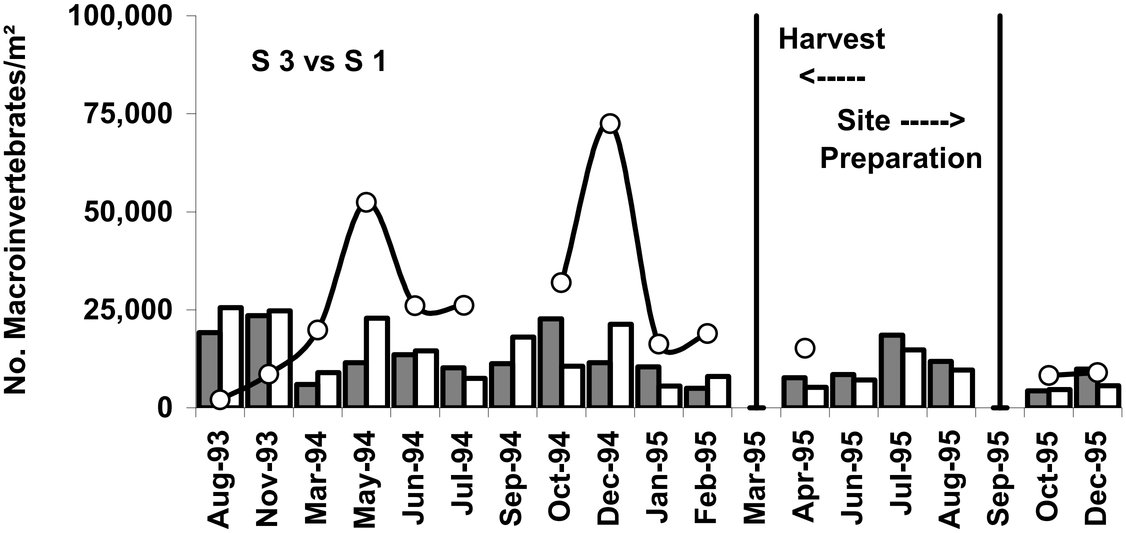

Figure 16. Mean total macroinvertebrate density (No./ m²) in S 3 –SMZ and Chemically Site Prepared - inside (dark bar) and below (white bar) the clearcut and in the Reference Stream (line) in Camden, Alabama from August 1993 to December 1995.

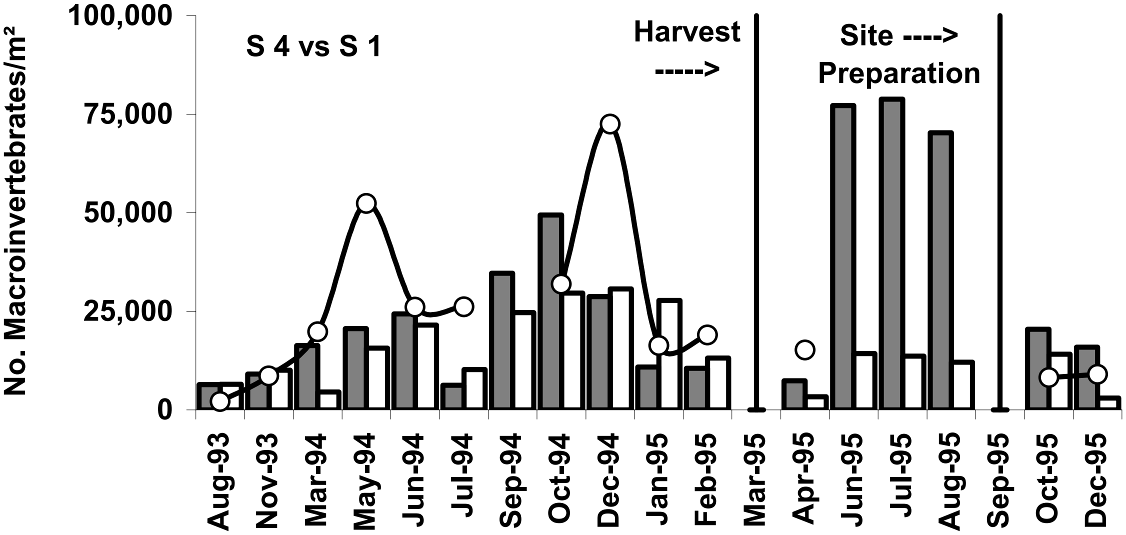

Figure 17. Mean total macroinvertebrate density (No./ m²) in S 4 – no SMZ and Mechanically Site Prepared - inside (dark bar) and below (white bar) the clearcut and in the Reference Stream (line) in Camden, Alabama from August 1993 to December 1995.

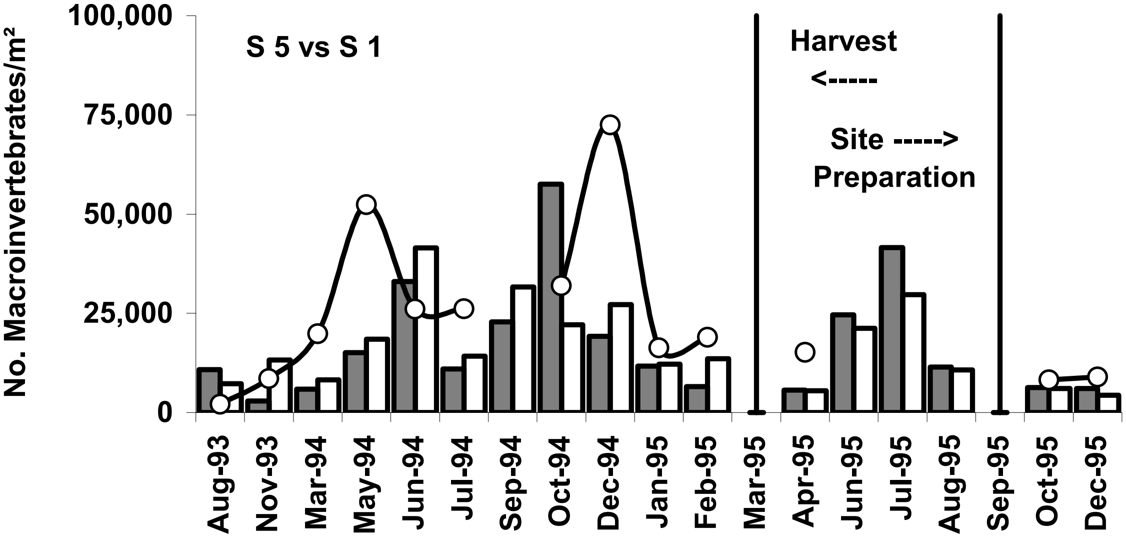

Figure 18. Mean total macroinvertebrate density (No./ m²) in S 5 –SMZ and Mechanically Site Prepared - inside (dark bar) and below (white bar) the clearcut and in the Reference Stream (line) in Camden, Alabama from August 1993 to December 1995.

In general, among all streams during the pre disturbance period, riffle habitats were more densely populated by macroinvertebrates than the pool habitats. Others studies have reported that riffles tend to support higher macroinvertebrate densities than pools (Gordon *et al.* 1992). However, macroinvertebrate densities from pools and riffles in S 3 differed little. S 3 was spring fed and water levels remained relatively constant with little change in temperature throughout the study period. Water temperature in S 3 remained between 15 and 20°C throughout the study. The lower water temperatures in S 3 may have contributed to higher dissolved oxygen levels in pools so that macroinvertebrate densities were similar to those found in riffles.

Among all streams, macroinvertebrate density was usually lower in winter, increasing through spring and summer to reach maximum densities in fall (Figures 15 through 18). Similar results have been reported in other studies in Southeastern US streams (Cowell *et al.* 2004). Although S 1 was dry during part of the predisturbance phase, on at least six sampling dates macroinvertebrate density was higher in the reference stream than in S 3, S 4 or S 5. Run-off from crops growing in the headwaters of W 1 and W 2 may have contributed nitrates (Table 3) to S 1 and S 2 resulting in higher macroinvertebrate densities compared to S 3, S 4 and S 5. Seasonal density variations of smaller magnitude were observed in S 3 probably because of the lack of water level and temperature fluctuations during the year, as springs fed the stream providing more stable conditions.

Except for S 3, mean density on most dates for sites within the clearcut and those below differed little during the predisturbance period. Also, mean density in S 1 on most dates was similar to that in each of the other streams except S 3. An ANOVA test for samples taken during the predisturbance period revealed no significant ($p < 0.05$) differences between macroinvertebrate densities at stations within the clearcut and below.

Following harvest, in the streams with no SMZ, S 2 and S 4, higher macroinvertebrate densities were found inside the clearcut areas than below, however only in S 4 (Figure 15 and 17) were the differences significant ($p < 0.05$) based on an ANOVA. This difference was probably related to the lack of riparian vegetation that was removed to the edge of the stream bank in S 4 during harvest. Thus, much of the channel in S 4 within the clearcut was exposed to direct sunlight because all but 10% of the riparian vegetation was removed during harvest (Figure 2). Along S 2 the percent canopy cover was reduced gradually over a period of several weeks because of the difficulty of removing trees on the steep banks of the stream. However, by June 1995 large masses of filamentous algae were observed in the clearcut areas of both streams, although much more in S 4.

After harvest, in the streams with an SMZ, S 3 and S 5 (Figure 16 and 18), an ANOVA revealed no significant ($p < 0.05$) differences for total density between the clearcut areas and below. Also, little filamentous algae was observed within the clearcut area of S 3 and S 5 post harvest because the canopy cover was still 85 to 90%. Total macroinvertebrate density in S 1 during this period was relatively low on the one date when sampling was possible.

To illustrate the importance of the Chironomidae (midge larvae) in the benthic fauna, the density of the midges compared with the “Others” category across all phases of the study appears in Figure 19. During the entire study, Chironomidae density exhibited similar trends to that of the total macroinvertebrate population in all streams. Midges usually comprised a major portion of the total macroinvertebrate community.

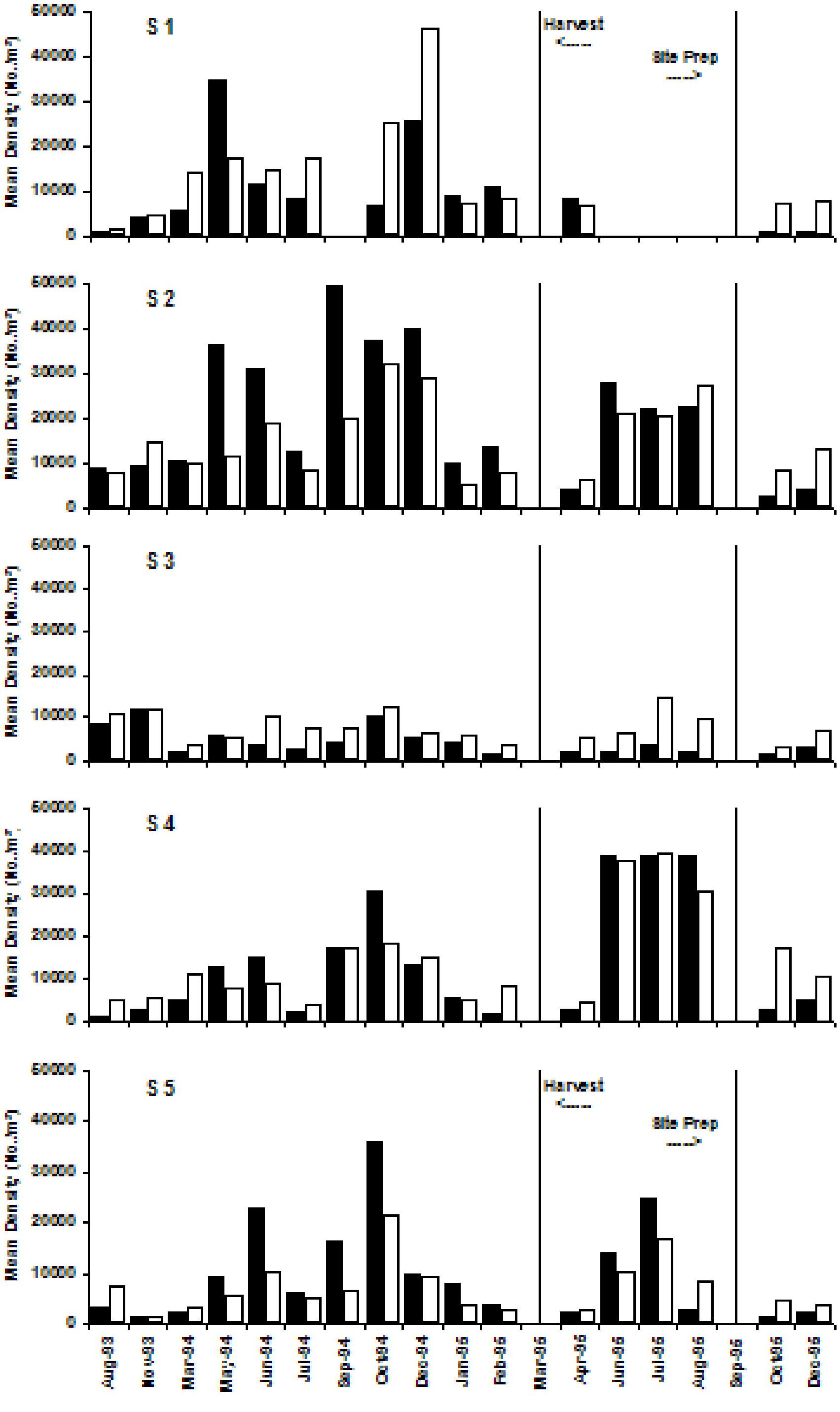

Figure 19. Mean density of Chironomidae (dark bars) and Other macroinvertebrates (clear bars) per m² at S 1 and within the clearcut area at S 2 - S 5 in Camden, Alabama from August 1993 to December 1995.

Population densities of benthic macroinvertebrates in streams are often highly variable (Corkum 1991; Downes *et al.* 2000) and some densities recorded during this study were noticeably higher than those found in other studies. One possible explanation was the small mesh size used in this study (250-µm) compared to that often used by other authors (350 to 600-µm). Nevertheless, Corkum (1991) reported similar densities from large streams when using 250-µm mesh sieves. Little published data was found on macroinvertebrate densities from 1st-order Coastal Plain streams undergoing timber harvest. Using a 350-µm mesh portable invertebrate box sampler, Boschung and O'Neil (1981) reported density of 700 organisms/m² before clearcut and 1,700/m² after harvest in streams in the Piedmont region of Alabama.

2. Effects of Clearcut and Site Preparation on Macroinvertebrate Density

Following harvest, densities inside the clearcut area from S 4 and S 5 were significantly higher ($p<0.05$) than those found in the reference stream S 1, whereas densities in S 2 and S 3 were not statistically different from S 1 based on RIA (Figures 20 and 21). One reason for the differences in density between S 4 and S 1 was related to the sharp increases in density (June, July and August 1995) in S 4 compared to predisturbance values. S 4 was one of the treatments with no SMZ. In S 2, the other stream with no SMZ, macroinvertebrate densities post harvest differed little compared to those measured during the predisturbance period (see also Figure 15). Therefore, based on RIA, no significant differences were detected between S 2 and S 1 (Figure 20). Also, as mentioned earlier, unlike riparian vegetation in S 4, canopy cover was reduced gradually in S 2 because of the difficulty of removing trees along the banks of the stream.

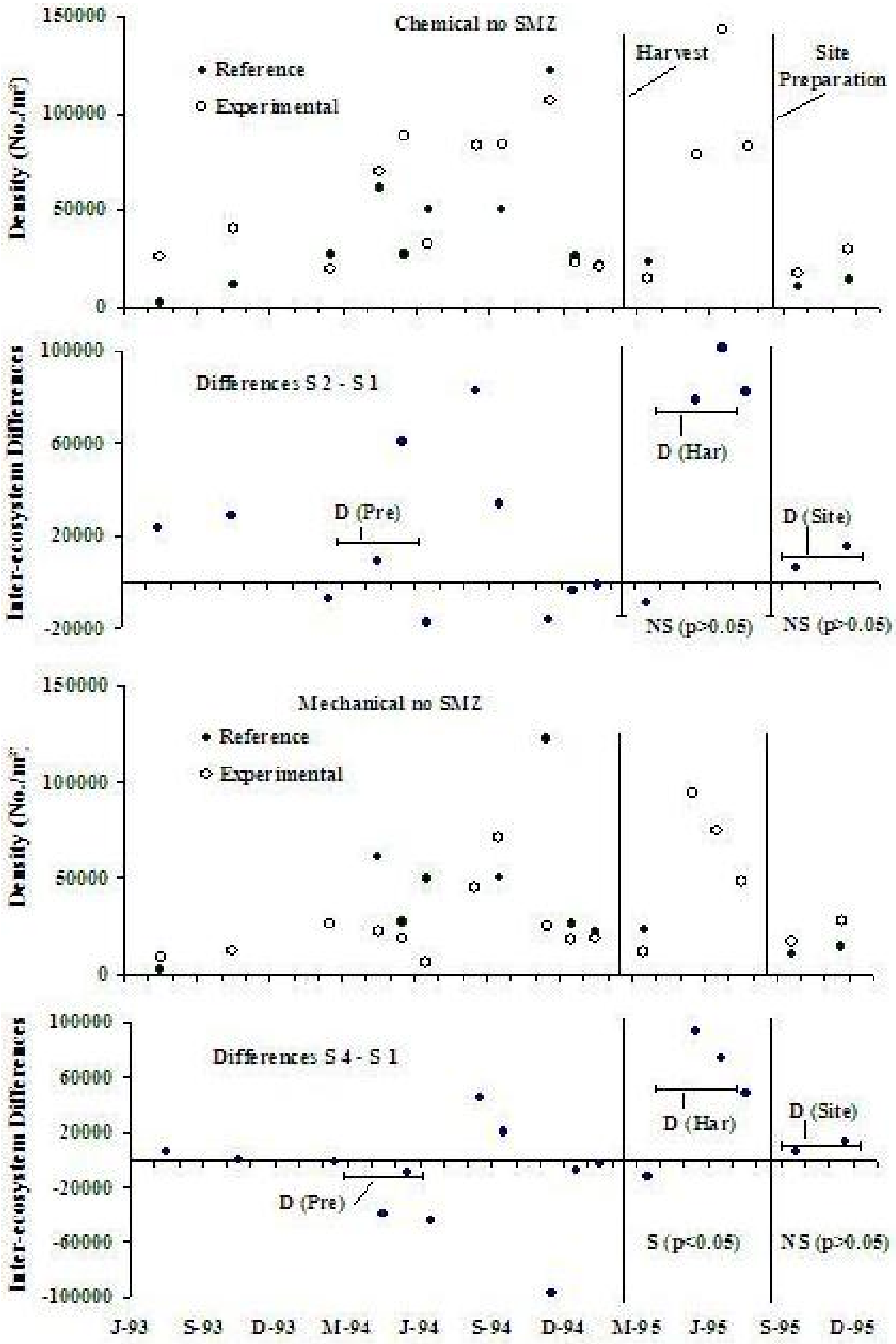

Figure 20. Mean density of total macroinvertebrates measured in S 1(reference stream) and within the clearcut of S 2 and S 4 with no SMZ. Also shown are the inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed differences are shown for the three phases of the study pre-disturbance (D-Pre), post-harvest (D-Pre) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation, was analyzed against the pre-disturbance period.

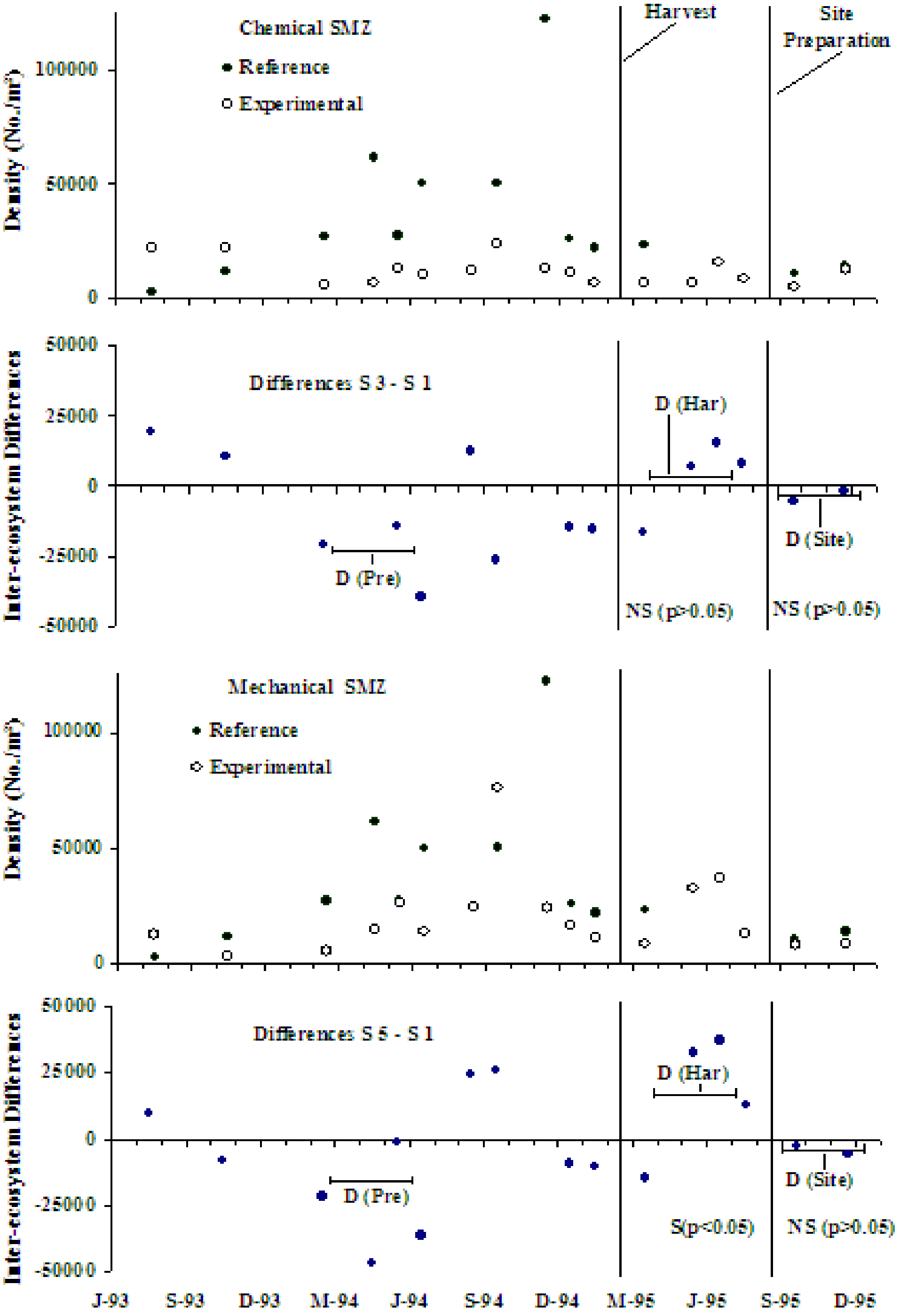

Figure 21. Mean density of total macroinvertebrates measured in S 1 (reference stream) and within the clearcut of S 3 and S 5 with an SMZ. Also shown are the inter-ecosystem differences between each experimental stream and the reference plus the mean inter-watershed differences are shown for the three phases of the study pre-disturbance (D-Pre), post-harvest (D-Pre) and post-site preparation (D-Site). Each period, post-harvest and post-site preparation, was analyzed against the pre-disturbance period.

In S 5 with an SMZ, mean densities after harvest differed little from those measured during the pre-disturbance phase. It was not clear why RIA detected significant differences between S 5 and S 1. However the reason may be that on 7 of 10 dates during the predisturbance phase, mean densities in S 1 were higher than that measured in S 5.

The lack of significant differences between S 3 and S 1 was probably related to the small variability in density observed within the clearcut in S 3 during the post harvest phase compared to the predisturbance period. However, the trend was evident that sites in S 4 and S 2 with no SMZ had greater increases in macroinvertebrate density than S 3 and S 5 with an SMZ. Corkum (1991) found that benthic macroinvertebrates density and biomass were often greater in open unshaded areas than in reaches with overhanging canopies, thus reflecting differences in abundance and production of benthic producers.

When compared with undisturbed streams, Carlson *et al.* (1990) reported higher densities of benthic macroinvertebrates from clearcut areas in Oregon 5 years after harvest. Murphy and Hall (1981) found similar results 10 years after harvest in low order streams in Oregon. Greater benthic densities were found in low order California streams with logged watersheds without an SMZ compared to undisturbed controls (Newbold *et al.* 1980). These authors suggested that logging affected macroinvertebrate densities because of a shift in the food base from detritus to algal production. In my study, based on mean chlorophyll *a* values (Table 5), higher algal biomass in S 4 and S 2 compared to S 1 apparently supported the higher benthic macroinvertebrate densities found in those streams after harvest.

Following site preparation, the mean density of macroinvertebrates from each watershed receiving a clearcut was not significantly (P>0.05) different from that found in the reference stream S 1 (Figure 20 and 21). The lack of significant differences among treatments suggested that chemical and mechanical site preparation had little effect on macroinvertebrate communities in these streams. Similar effects of imazapyr (Fowlkes *et al.* 2003) and glyphosate (Tu *et al.* 2001) on benthic macroinvertebrates have been reported in other studies.

3. Taxa Richness, Species Diversity and Community Structure

All streams had similar taxa richness (TR) during the pre disturbance period with the mean number of taxa collected at a single stream ranging from a high of 86 in S 1 during June 1994 to a low of 33 in S 3 during February 1995 (Figure 22). RIA revealed no significant differences in mean taxa richness among all streams during this period. Across all streams, Chironomidae was the most diverse family represented with 76 total taxa and providing, in general, about 44 % of the taxa collected from core samples. Taxa occurring in greatest numbers during the pre-disturbance period were midges of the genus *Tanytarsus* spp. and *Rheotanytarsus* spp., the ephemeropteran *Baetis* spp. the coleopteran *Psephenus herricki* and oligochaetes. Both midges are filtering collectors that filter fine particulate BOM from the water column. *Baetis* is a gathering collector that feeds on BOM in the substrate. *Psephenus herricki* is a grazer that feeds by scrapping algae and BOM from the substrate. Oligochaetes are also gathering collectors that feed on BOM (Merritt and Cummins 1996).

After harvest, taxa richness ranged from a mean low of 37 in S 3 to a maximum of 86 in S 2 (Figure 22). The reference stream was dry during most sampling dates scheduled in the post harvest period. The single sample collected from the reference stream during this period was not selected for taxa identification. Therefore, no post- harvest

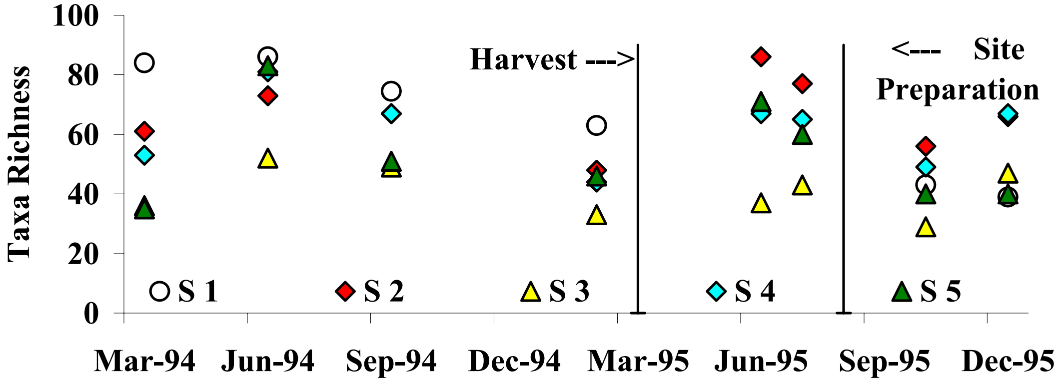

Figure 22. Mean taxa richness from selected dates for macroinvertebrates collected in S 1 (reference stream) and within the clearcut of the four experimental streams.

comparisons with S 1 were possible. Compared to previous summer, taxa richness after harvest was slightly lower inside the clearcuts of all experimental streams except S 2.

Although macroinvertebrates were not identified for the one date sampled in S 1 post harvest, RIA generated values based on predisturbance samples. However, no statistical differences in taxa richness were detected among all streams post harvest. Even though chlorophyll *a* concentrations increased in all streams receiving clearcuts (Figures 9 through 12), this change in algal biomass resulted in no increase in taxa richness.

Following site preparation, RIA detected no statistical differences in benthic taxa richness among the experimental streams compared to S 1. Based on these results, both chemical and mechanical site preparation techniques appeared to have no influence on taxa richness. Fowlkes *et al.* (2003) experimenting with in situ microcosms in north Florida, found that imazapyr had little effect on macroinvertebrate taxa richness and abundance.

Richness for the more sensitive taxa in the orders Ephemeroptera, Plecoptera and Trichoptera (EPT) was similar among all streams during the pre disturbance period with S 1 having the highest richness (Table 8). EPT richness values in the range of 12 to 14 like those found in this study are typical in undisturbed Coastal Plain streams (Personal observation, E. C. Webber 2005). During all phases of this study no significant differences in EPT richness were found among streams.

Table 8. Mean EPT index before harvest, after harvest and after site preparation at five streams in Camden Alabama from March 1994 to December 1995. Dash means no samples were collected due to drought.

Station	Pre-Disturbance	Post-harvest	Post-Site Preparation
S 1	13	---	8
S 2a	12	14	11
S 2b	13	10	12
S 3a	11	8	8
S 3b	9	7	6
S 4a	12	11	11
S 4b	11	11	8
S 5a	9	7	6
S 5b	11	12	5

Imazapyr was present in the chemically treated streams S 2 from August 27 to October 6 1995 and briefly in S 3 (Figure 6). The small changes in the EPT index in both streams seemed to suggest natural variation instead of effects from the herbicide mixture on these more sensitive taxa. Kaller and Hartman (2004) found that EPT taxa richness significantly decreased when fine silt particles increased in the stream substrate. Except for S 1, more silt and sediment were observed in all the streams after both harvest and site preparation; hence, the possibility existed that small changes in EPT richness may have occurred following the disturbances. However, based on the data collected in this study, changes in the EPT index appeared to reflect natural variability rather than treatment effects.

Macroinvertebrate diversity was similar among all streams before harvest with Shannon -Weaver Diversity values ranging from a low of 3.03 in S 2 to a high of 3.79 in S 4 (Table 9). Diversity values measured during the pre disturbance phase of this study were greater than 3.0, and 3.0 is considered typical for undisturbed and unstressed streams (Wilhm and Dorris 1968). A Tukey's test found no significant differences ($p > 0.05$) in species diversity among all streams during the pre disturbance period. After harvest, diversity in the experimental streams changed little from that measured prior to harvest.

Table 9. Mean Shannon-Weaver diversity index (H') during pre-disturbance, post harvest and post site preparation in five streams near Camden Alabama from March 1994 through December 1995.

Station	Pre-Disturbance	Post-harvest	Post-Site Preparation
S 1	3.71	---	3.09
S 2a	3.03	3.50	3.46
S 2b	3.17	3.22	3.05
S 3a	3.07	3.02	2.90
S 3b	3.35	2.91	2.82
S 4a	3.25	3.25	3.19
S 4b	3.79	3.26	2.95
S 5a	3.24	3.19	2.99
S 5b	3.25	3.38	3.25

Diversity in S 1 was not measured during this period because the single sample collected was not selected for taxa identification during the random sampling. However, no significant differences ($P>0.05$) were detected among the streams during the post harvest period. Harvest apparently had no effects on macroinvertebrate species diversity. In east central Alabama, Boschung and O'Neil (1981) found no differences in diversity among streams subjected to clearcut harvest. Diversity values in their study were similar to values found in this study. Also, after site preparation no significant differences were detected among streams, or when compared to S 1.

Among all streams, benthic community structure throughout this study consisted predominantly of five functional feeding groups including collectors, both gathering (GC) and filtering (FC), predators (P), shredders (SH) and scrapers (SC). During each phase of the study the two groups of collectors comprised 46 to 65 % of the total fauna, followed by predators with 7 to 27 % of the fauna, scrapers with 12 % or less of the total fauna and shredders with 17% or less of the fauna (Table 10). These findings differed slightly from the River Continuum Concept (RCC), which assumes that about one third of the total macroinvertebrate community in headwater streams usually consists of shredders (Vannote *et al.* 1980). Even though heavy canopy cover was present along all streams prior to harvest; shredders comprised a relatively small percentage of the total fauna during this phase and throughout the study in S 1.

Among these five functional feeding groups seven taxa tended to dominate in all streams throughout the study. Gathering-collectors included species of *Baetis* and oligochaetes. Filtering-collectors were usually dominated by the dipterans *Tanytarsus* spp. and *Rheotanytarsus* spp. Another group of small dipterans, the Ceratopogonidae were the dominant predators identified in samples. These small midges probably preyed on tiny invertebrates such as water mites and crustaceans common in the streams.

Table 10. Percentages of the total macroinvertebrate fauna by functional feeding group collected before and after harvest and after site preparation, inside the clearcut areas in five stream in Camden, Alabama during March 1994 to December 1995. Dash indicates no collection due to drought. (FC= Filtering-Collectors, GC= Gatherers-Collectors, P= Predators, SC= Scrapers-Piercers, SH= Shredders).

	Pre Disturbance (n=4)					Post Harvest (n=2)					Post Site Preparation (n=2)				
	FC	GC	P	SC	SH	FC	GC	P	SC	SH	FC	GC	P	SC	SH
S 1	30	31	7	1	2	--	--	--	--	--	10	40	13	0	2
S 2a	49	16	10	1	1	17	41	13	1	1	13	37	7	2	0
S 3a	12	43	7	6	7	13	42	12	12	10	9	50	8	1	15
S 4a	18	33	19	4	2	33	25	9	2	1	13	47	12	2	8
S 5a	23	40	15	1	6	21	25	27	8	1	7	39	24	4	17

Another group of dipterans, species of *Polypedilum* were the dominant shredders. So in the streams, shredders, like the predators, were not represented by larger macroinvertebrates such as certain stoneflies and caddisflies, but by minute midges. In fact, species of *Polypedilum* also feed occasionally as gathering-collectors. Coleopterans were the dominant scrapers consisting of the species *Psephenus herricki.* Other taxa occasionally occurred in high numbers in selected streams along with these seven, however no trends were evident with regard to treatment effects.

The seven taxa and their percent composition of the total fauna during each phase of the study appear in Table 11 for sites within the clearcut. These taxa were also common in S 1 although data are not shown because the stream was dry during much of the post harvest phase.

After harvest small changes in community structure were observed in all streams, except S 1 that had no data for comparable dates (Tables 10 and 11). Scrapers increased slightly in S 2, decreased in S 4 and increased considerably in S 3 and S 5 in the forms of the caddisfly *Glossosoma spp*., the mayfly *Habrophlebiodes spp.* and the snail *Elimia*

Table 11. Percent composition of the most common macroinvertebrate taxa in the five dominant functional feeding groups (FFG) collected inside the clearcut areas of four streams in Camden, AL. before disturbance (PreDist), post harvest (PostHarv) and post site preparation (PostSite).

	S 2 a			S 3 a		
FFG / Taxa	PreDist	PostHarv	PostSite	PreDist	PostHarv	PostSite
	n=4	n=2	n=2	n=4	n=2	n=2
Gatherer-collectors						
Baetis spp.	2	10	14	8	11	11
Oligochaetes	1	5	11	12	21	22
Filterer-collectors						
Tanytarsus spp.	39	10	1	<1	6	<1
Rheotanytarsus spp.	9	4	<1	3	<1	3
Predators						
Ceratopogonidae	4	3	3	4	9	5
Scrapers						
Psephenus herricki	5	7	3	<1	<1	2
Habrophlebiodes spp.	1	1	2	<1	<1	<1
Shredders						
Polypedilum spp.	<1	3	8	7	10	15

	S 4 a			S 5 a		
FFG / Taxa	PreDist	PostHarv	PostSite	PreDist	PostHarv	PostSite
	n=4	n=2	n=2	n=4	n=2	n=2
Gatherer-collectors						
Baetis spp.	8	8	3	11	16	19
Oligochaetes	7	1	18	2	2	10
Filterer-collectors						
Tanytarsus spp.	3	25	3	5	13	2
Rheotanytarsus spp.	5	<1	2	12	5	3
Predators						
Ceratopogonidae	11	1	10	7	5	15
Scrapers						
Psephenus herricki	9	12	2	<1	5	<1
Habrophlebiodes spp.	4	2	1	1	8	4
Shredders						
Polypedilum spp.	3	5	10	5	1	17

spp. Increases in scrapers in S 2 and S 4 were expected because of the treatment effect of no SMZ. However, increases in S 3 and S 5 with an SMZ may only reflect seasonal variability. The lack of canopy cover and more sunlight reaching these streams allowed more algae growth, although significantly higher ($P<0.05$) chlorophyll *a* values were found in all experimental streams after harvest. This may explain why S 5 also had increases in scrapers during this period.

Shredders represented by midges of the Chironomidae, *Polypedilum* spp., increased slightly in S 2 and S 4 with no SMZ probably because of the large masses of filamentous algae observed in these two streams. These midges are known to feed on filamentous algae (Henriques-Oliveira *et al.* 2003). The increase of shredders in S 2 and S 4 was the opposite effect of that expected in these streams with no SMZ.

Slight increases of the mayfly *Baetis* spp. (GC) in S 2, S 3 and S 5 may have been related to the increased algal communities in all streams. However, it was not clear why this increase was not observed in S 4. Wallace and Gurtz (1986) identified significant increases in diatom consumption by the mayfly *Baetis* spp. in North Carolina streams after clearcut. However, these changes in scrapers and other groups appeared to be more related to natural variability than harvest effects.

After site preparation the benthic fauna in all streams continued to be dominated by collectors and overall the community structure was similar to that observed in the reference stream (Table 10). Macroinvertebrate communities resembled those found during the pre disturbance sampling although shredders constituted a significant percentage of the total fauna in S 3, S 4 and S 5. Overall, considering the macroinvertebrate communities found in the fall of 1995 in all experimental streams and comparing them to S 1, neither chemical nor mechanical site preparation had a major influence in changes of macroinvertebrate community structure.

I. Summary

The experimental streams in the Camden study presented interesting changes both after harvest and after site preparation. Only natural conditions affected the reference stream with an undisturbed watershed during the entire study; therefore, changes in physicochemical conditions and benthic communities in S 1 apparently reflected only natural variations due to seasons. Drought conditions in the reference stream weakened the possibility of comparing with treated streams and analyzing results after harvest. After harvest there were increases in sediments observed at all streams except S 1, and small decreases in BOM in all streams except S 5. Higher water temperatures were measured in the streams without SMZ after harvest. Shifts in macroinvertebrate communities observed in the experimental streams may have reflected changes in the watersheds because of the clearcuts. As more sunlight reached the streams, it allowed larger primary producers (e.g. filamentous benthic algae) to flourish and consequently provide more food for primary consumers such as scrapers. However, less percentage of scrapers was found in the streams without SMZ. After site preparation sediment increases were observed, mainly at those sites mechanically prepared and BOM increased at all streams except S 3. However, some of these increases were result of the increased runoff associated with Hurricane Opal. Algal communities increased after site preparation suggesting no detrimental effect of the imazapyr and glyphosate on primary producers in the streams; and macroinvertebrate communities were apparently not affected by either chemical or mechanical treatment. Macroinvertebrate diversity and taxa richness did not significantly change in any stream during the study. Overall, mechanical site preparation in clearcuts without SMZ appeared to be the method that most affected the biota. Also, the herbicides imazapyr and glyphosate used in the concentrations applied in treatments with an SMZ had no harmful impacts on aquatic biota.

The structure and function of stream communities is affected by food availability and habitat structure (Vannote *et al.* 1980). During the Camden study no major changes in community structure were observed in the experimental streams and RIA did not detect significant differences. The few sample dates available after site preparation could be one of the weaknesses when using this statistical approach. Future studies should be designed with sampling conducted at least one year after disturbances (harvest or site preparation) in order to examine seasonal changes before and after site preparation. This could reduce data interpretation problems when comparing seasonally dependant variables such as periphyton and macroinvertebrates. Macroinvertebrate communities may recover within a few months to several years after disruption (Heckman 1983, Molles 1985) but some disturbances can produce long-term changes in habitats that recovery will not occur until the natural habitat is restored (Wallace 1990). Furthermore, the recovery will depend on the spatial scale of the disturbance, position within the stream network, timing in relation to the life history stages of the organisms and their dispersal abilities (Wallace 1990).

The use of SMZ helped mitigate some impacts to aquatic biota from the disturbances associated with clearcut harvest. The 11-m SMZ used in this study was wide enough to avoid any significant water temperature changes among streams. The 11-m SMZ also greatly reduced herbicide runoff and/or leaching to S 3. However, the

11-m SMZ did not prevent significant increases in algal biomass in S 3 and S 5. Therefore, timber harvest using wider riparian zones should be tested. For example, Kiffney *et al.* (2003) and Newbold *et al.* (1980) concluded that 30-m SMZ are needed to reduce biotic changes associated with clearcuts. Moreover, the stream management zones used in this study were limited to the main channel leaving smaller tributaries completely exposed within the clearcuts, which allowed more runoff and consequently, more sediment to reach the streams.

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APPENDIX I

Table 1. Composite list of taxa, tolerance value (TV) and functional feeding group (FFG) when known, presence at a sampling site (+) and total number of taxa per site collected in Camden, Alabama from March 1994 through December 1995.

AQUATIC INSECTS	TV	FFG	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta			+	+	+			+	+	+	+
Coleoptera							+	+			
Dryopidae											
Helichus spp. adults	5	GC			+						
Elmidae	5	GC	+	+	+	+	+	+	+	+	+
Ancyronyx varigatus	6	GC				+	+	+			+
Dubiraphia spp.	6	SC						+		+	+
Elmidae adults	5	SC						+		+	
Macronychus glabratus	4	SH								+	
Optioservus spp.	4	SC		+	+	+	+		+		
Optioservus spp. adults	4	GC		+		+	+				
Oulimnius latiusculus	4	SC	+	+	+	+	+	+	+		+
Oulimnius latiusculus adults	4	GC	+								
Promoresia spp.	4	SC							+		
Stenelmis spp. adults	7	GC	+	+	+	+	+		+		+
Psephenidae											
Psephenus herricki	4	SC	+	+	+	+	+	+	+	+	+
Psephenus herricki adults	4			+							
Ptilodactylidae											
Anchytarsus bicolor	5	SH	+	+	+	+	+		+	+	+
Collembola	3	GC	+	+	+	+				+	
Isotomidae					+	+	+	+	+	+	+
Sminthuridae	3	GC	+	+	+		+	+		+	
Diptera			+	+	+	+	+	+	+	+	+
Diptera adults			+	+	+	+	+	+	+	+	+
Diptera pupae			+	+	+	+	+	+	+	+	+
Ceratopogonidae	6	P	+	+	+	+	+	+	+	+	+
Atrichopogon spp.	6							+			
Bezzia/Palpomyia gp.	6	P	+	+	+	+	+	+	+	+	+
Chaoboridae	8	P						+			
Chironomidae	7	GC	+	+	+		+	+	+	+	+
Ablabesmyia spp.	8	P					+	+	+		+
Brillia spp.	5	SH	+								
Chaetocladius spp.	6	GC	+	+						+	
Chironomie	7	GC					+				

Appendix I. Table 1. Continued…

AQUATIC INSECTS	TV	FFG	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera											
Chironomidae											
Chironomini	8	GC		+	+	+	+	+	+	+	+
Cladotanytarsus spp.	7	FC	+	+				+			
Corynoneura spp.	7	GC	+	+	+	+	+	+	+	+	+
Cricotopus bicinctus	7	GC		+	+		+	+			
Cricotopus spp.	7	GC	+	+	+						
Cricotopus tremulus gp.	7	GC	+	+							
Cricotopus/Orthocladius	7	GC	+	+	+	+	+		+		
Cryptochironomus spp.	8	P		+	+	+				+	
Cryptotendipes spp.	6	GC						+			
Demicryptochironomus cuneatus	8	GC	+	+	+						
Dicrotendipes spp.	8	GC						+	+		
Diplocladius cultriger	8	GC	+		+		+		+		
Djalmabatista spp.	3	P					+	+			
Eukiefferiella claripennis gp.	8	GC	+			+	+	+		+	+
Glyptotendipes spp.	10	FC								+	
Harnischia spp.	8	GC		+					+		
Heterotrissocladius macidus gp.	8	GC		+							
Hydrobaenus pilipes gp.	8	GC				+					
Krenopelopia spp.	6	P		+	+				+	+	+
Krenosmittia spp.	6	GC	+	+	+	+	+	+	+	+	+
Labrundinia spp.	7	P									+
Larsia spp.	6	P	+	+	+	+	+	+	+	+	+
Micropsectra spp.	7	GC			+		+	+	+	+	+
Microtendipes pedellus gp.	6	FC						+			
Monopelopia spp.	6	P		+	+		+	+	+	+	+
nocladius spp.	3	GC		+					+		
tarsia spp.	8	P		+	+	+		+		+	
Nilotanypus spp.	6	P	+	+	+	+	+	+	+	+	+
Nilothauma spp.	2	GC		+							
Nimbocera pinderi	6			+							
Orthocladiie	6	GC	+	+	+	+	+	+		+	
Parachaetocladius spp.	6	GC	+	+	+	+	+	+	+		
Parachironomus spp.	10	P	+								
Paracladopelma spp.	7						+				
Paracricotopus spp.	6	GC						+			
Parakiefferiella spp.	6	GC								+	+
Parakiefferiella triquetra	4	GC	+						+		
Paralauterborniella nigrohalteralis	8	GC				+			+	+	
Parameri spp.	6	P	+		+		+	+		+	
Parametriocnemus spp.	5	GC	+	+	+	+	+	+	+	+	+
Parasmittia spp.	6		+								
Paratanytarsus spp.	6							+			
Paratendipes spp.	8	GC			+			+	+	+	+
Pentaneura spp.	5	GC						+			

Appendix I. Table 1. Continued…

AQUATIC INSECTS	TV	FFG	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera											
Chironomidae											
Polypedilum (P.) convictum	7	SH	+	+	+	+	+	+	+	+	+
Polypedilum (P.) fallax	7	SH	+	+	+	+	+				
Polypedilum (P.) illinoense	6	SH	+		+		+	+	+	+	+
Polypedilum (T.) halterale	7	SH		+	+	+	+	+	+	+	+
Polypedilum (T.) scalaenum gp.	7	SH	+	+	+	+	+	+	+	+	+
Polypedilum spp.	6	SH	+	+							+
Potthastia longima gp.	4	GC					+				
Procladius spp.	9	P						+			
Pseudorthocladius spp.	0	GC			+		+				
Psilometriocnemus spp.	6	GC		+							
Rheocricotopus spp.	6	GC	+	+						+	
Rheotanytarsus spp.	6	FC	+	+	+	+	+	+	+	+	+
Robackia demeijerei	8	GC	+	+	+		+			+	+
Saetheria spp.	4	GC						+			
Stempelli spp.	4	GC	+	+	+				+		
Stempellinella spp.	4	GC	+	+	+	+		+	+	+	+
Sublettea coffmanni	6	FC									+
Tanypodie	6	P	+	+	+		+	+	+		+
Tanypodie pupae	6			+							
Tanytarsini	6	FC								+	
Tanytarsus spp.	7	FC	+	+	+	+	+	+	+	+	+
Thienemannia spp.	6		+				+		+	+	
Thienemanniella spp.	6	GC	+	+	+	+	+	+	+	+	+
Thienemannimyia complex	6	P	+	+	+	+		+	+	+	+
Tribelos spp.	5	GC	+								
Tvetenia bavarica gp.	5	GC	+	+	+	+	+	+	+	+	+
Zavrelimyia spp.	8	P			+			+	+		+
Culicidae	8	FC					+	+	+	+	+
Culex spp.	8	FC	+	+		+		+	+	+	+
Dixidae											
Dixa spp.	1	GC					+				
Empididae											
Hemerodromia spp.	6	P	+	+	+	+	+	+		+	+
Psychodidae											
Pericoma/Telmatoscopus	10	GC		+							
Simuliidae	6	FC					+				
Simulium spp.	6	FC	+	+	+	+	+	+	+	+	+
Tanyderidae											
Protoplasa fitchii			+			+	+				
Tipulidae	3	SH	+	+	+				+		
Hexatoma spp.	4	P	+	+	+	+	+	+	+	+	+
Pseudolimnophila spp.	2	P	+	+	+	+	+	+	+	+	+
Tipula spp.	4	SH	+		+		+			+	+
Tipulidae pupae	3						+				

Appendix I. Table 1. Continued…

AQUATIC INSECTS	TV	FFG	1C	2A	2B	3A	3B	4A	4B	5A	5B
Ephemeroptera			+	+	+			+			
Baetidae	4	GC						+	+		+
Baetis spp.	6	GC	+	+	+	+	+	+	+	+	+
Caenidae											
Caenis spp.	7	GC	+	+	+	+	+	+	+	+	
Ephemeridae											
Hexagenia spp.	6	GC		+				+	+		+
Heptageniidae											
Stenonema spp.	5	SC		+	+			+	+		+
Leptophlebiidae											
Habrophlebia vibrans	2	GC						+			
Habrophlebiodes spp.	2	SC	+	+	+	+		+	+	+	+
Hemiptera		P		+		+					
Mesoveliidae											
Mesovelia spp.		P							+		
Veliidae		PI			+						
Rhagovelia spp.		PI					+				
Lepidoptera			+	+			+			+	
Megaloptera											
Corydalidae											
Nigronia spp.	2	P		+		+					
Odonata		P							+		
Aeshnidae											
Boyeria spp.	3	P		+							
Calopterygidae											
Calopteryx spp.	5	P			+	+			+	+	
Cordulegastridae											
Cordulegaster spp.	3	P								+	+
Gomphidae	1	P		+	+	+	+	+	+	+	+
Erpetogomphus desigtus	5	P		+	+	+					
Progomphus spp.	5	P						+			
Stylogomphus albistylus	0	P	+		+						
Plecoptera			+	+	+	+	+	+	+	+	+
Chloroperlidae											
Alloperla spp.	0	GC	+	+	+	+		+	+	+	+
Leuctridae	0	SH	+								
Nemouridae	2	SH						+			
Amphinemura spp.	3	SH	+	+	+			+	+	+	+
Perlidae	1	P	+								+
Acroneuria spp.	1	P		+							
Eccoptura xanthenes	1	P	+	+	+	+	+		+		
Trichoptera				+	+	+	+	+	+	+	+
Calamoceratidae											
Anisocentropus pyraloides	3	SH	+		+						

Appendix I. Table 1. Continued…

AQUATIC INSECTS	TV	FFG	1C	2A	2B	3A	3B	4A	4B	5A	5B
Trichoptera											
Glossosomatidae											
Glossosoma spp.	0	SC	+	+	+	+	+	+	+	+	+
Hydropsychidae	4	FC	+	+	+	+	+	+	+	+	+
Cheumatopsyche spp.	6	FC		+	+		+	+	+	+	+
Diplectrona spp.	4	FC	+	+	+	+	+	+	+	+	+
Hydropsyche spp.	7	FC	+	+	+	+	+	+	+	+	+
Macrostemum carolina	4	FC		+		+				+	+
Macrostemum spp.	4	FC					+		+		
Hydroptilidae	4	PI		+				+			
Hydroptila spp.	6	PI						+			
Limnephilidae	4	SH									+
Neophylax spp.	3	SC								+	
Molannidae	6	SC		+							
Molanna spp.	6	SC	+		+	+					
Philopotamidae											
Chimarra spp.	4	FC		+	+	+					
Rhyacophilidae											
Rhyacophila spp.	4	P						+			
Amphipoda											
Gammaridae	4	GC	+	+		+	+				
Copepoda			+	+	+	+	+	+	+	+	
Calanoida			+	+	+	+	+	+	+	+	+
Harpacticoida			+		+		+	+	+	+	
Decapoda	6	SH						+			
Cambaridae	5	GC			+						
Gastropoda				+	+	+	+	+	+	+	+
Pleuroceridae											
Elimia spp.	5	SC		+		+	+	+	+		+
Hydracarina	5		+	+	+	+	+	+	+	+	+
Nematoda	5		+	+	+	+	+	+	+	+	+
Oligochaeta											
Lumbriculidae	8	GC	+							+	
Oligochaeta	10	GC	+	+	+	+	+	+	+	+	+
Ostracoda				+		+		+	+	+	+
Pelecypoda		FC	+			+					
Corbiculidae											
Corbicula fluminea	4	FC		+	+					+	
Turbellaria											
Plariidae	4		+	+	+			+	+	+	
Total number of taxa per sampling site			88	103	92	74	83	96	85	85	77

APPENDIX II

Table 1. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 18 March 1994.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta	0	0	1	0	0	0	0	0	0
Coleoptera									
Elmidae	0	0	1	3	6	1	0	3	3
Optioservus spp.	0	0	1	1	6	0	1	0	0
Oulimnius latiusculus	9	1	0	0	2	3	0	0	0
Stenelmis spp. Adults	0	0	1	1	1	0	1	0	2
Elmidae adults	0	0	0	0	0	1	0	0	0
Psephenidae									
Psephenus herricki	1	2	19	0	0	0	2	0	2
Ptilodactylidae									
Anchytarsus bicolor	2	0	1	4	3	0	0	1	0
Collembola									
Isotomidae	0	0	2	0	0	0	0	0	0
Sminthuridae	2	0	2	0	0	0	0	0	0
Diptera	1	2	12	1	1	2	2	2	1
Diptera adults	3	0	1	1	0	0	1	0	0
Diptera pupae	2	3	5	0	0	0	0	1	0
Ceratopogonidae	0	14	69	7	0	10	0	1	1
Bezzia/Palpomyia gp.	6	13	0	4	3	18	2	5	10
Chironomidae	0	0	0	0	0	0	0	0	1
Brillia spp.	1	0	0	0	0	0	0	0	0
Chaetocladius spp.	0	2	0	0	0	0	0	2	0
Corynoneura spp.	7	14	22	0	0	12	2	3	2
Cricotopus tremulus gp.	1	0	0	0	0	0	0	0	0
Cricotopus spp.	3	0	4	0	0	0	0	0	0
Cricotopus/Orthocladius	5	1	4	0	0	0	0	0	0
Cryptochironomus spp.	0	2	0	0	0	0	0	0	0
Demicryptochironomus cuneatus	3	0	0	0	0	0	0	0	0
Diplocladius cultriger	1	0	0	0	0	0	0	0	0
Eukiefferiella claripennis gp.	0	0	0	0	0	0	0	0	1
Krenopelopia spp.	0	4	0	0	0	0	0	0	0
Krenosmittia spp.	0	0	4	0	3	24	0	4	1
Larsia spp.	2	0	2	0	0	6	1	0	0
Micropsectra spp.	0	0	0	0	0	0	0	1	0
Nilotanypus spp.	2	2	0	0	0	0	1	0	0
Parachironomus spp.	1	0	0	0	0	0	0	0	0

Appendix II. Table 1. Continued…

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Paracladopelma spp.	0	0	0	0	1	0	0	0	0
Parakiefferiella triquetra	0	0	0	0	0	0	1	0	0
Parametriocnemus spp.	1	0	0	0	2	2	0	1	1
Paratendipes spp.	0	0	0	0	0	0	0	0	1
Pentaneura spp.	0	0	0	0	0	2	0	0	0
Polypedilum (P.) convictum	10	1	12	0	6	3	0	0	0
Polypedilum (P.) fallax	0	0	2	0	0	0	0	0	0
Polypedilum (P.) illinoense	0	0	0	0	0	1	0	0	0
Polypedilum (T.) halterale	0	0	22	11	3	1	0	0	7
Polypedilum (T.) scalaenum gp.	1	2	2	7	0	0	0	0	13
Polypedilum spp.	0	1	0	0	0	0	0	0	0
Rheocricotopus spp.	3	3	0	0	0	0	0	0	0
Rheotanytarsus spp.	9	5	8	0	0	0	1	0	34
Robackia demeijerei	0	2	0	0	9	0	0	1	0
Stempellinella spp.	0	2	0	0	0	0	0	0	0
Tanytarsus spp.	19	93	246	0	1	0	0	0	0
Thienemanniella spp.	0	0	0	4	5	3	1	1	0
Thienemannimyia complex	0	4	0	0	0	0	0	0	0
Tvetenia bavarica gp.	7	4	20	8	14	57	3	11	2
Orthocladiie	3	0	0	2	0	1	0	0	0
Tanypodie	0	2	0	0	0	0	0	0	0
Culicidae									
Culex spp.	4	1	0	0	0	0	0	0	0
Culicidae	0	0	0	0	1	0	0	0	0
Simuliidae									
Simulium spp.	24	3	8	1	0	128	9	14	6
Tipulidae									
Hexatoma spp.	1	16	34	0	3	5	2	3	4
Pseudolimnophila spp.	0	0	2	0	0	1	0	0	1
Tipula spp.	1	0	0	0	0	0	0	0	2
Tipulidae pupae	0	0	0	0	1	0	0	0	0
Ephemeroptera									
Baetidae	0	0	0	0	0	2	0	0	0
Baetis spp.	19	6	8	1	8	2	0	4	0
Caenidae									
Caenis spp.	0	0	0	0	2	0	0	0	0
Leptophlebiidae									
Habrophlebiodes spp.	0	2	1	0	0	1	1	0	0
Lepidoptera	0	1	0	0	0	0	0	0	0
Odonata									
Gomphidae	0	0	2	1	0	0	0	0	0

Appendix II. Table 1. Continued…

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Plecoptera	116	21	94	2	30	50	14	11	3
Chloroperlidae									
Alloperla spp.	27	5	14	0	0	6	14	3	3
Nemouridae									
Amphinemura spp.	4	0	2	0	0	2	1	3	6
Perlidae	8	0	0	0	0	0	0	0	0
Eccoptura xanthenes	2	1	0	1	2	0	0	0	0
Trichoptera	0	0	0	4	18	0	0	0	0
Glossosomatidae									
Glossosoma spp.	1	1	1	0	8	1	1	0	0
Hydropsychidae	6	0	0	1	1	1	0	1	3
Cheumatopsyche spp.	0	0	1	0	0	0	0	0	0
Hydropsyche spp.	2	0	0	0	0	0	1	0	0
Molannidae									
Molanna spp.	1	0	4	0	0	0	0	0	0
Rhyacophilidae									
Rhyacophila spp.	0	0	0	0	0	1	0	0	0
OTHER AQUATIC INVERTEBRATES									
Copepoda	0	0	5	0	1	0	0	0	0
Calanoida	5	4	7	0	0	0	0	0	0
Harpacticoida	1	0	1	0	2	0	1	1	0
Amphipoda									
Gammaridae	3	0	0	0	0	0	0	0	0
Gastropoda	0	0	3	0	0	0	0	0	0
Pleuroceridae									
Elimia spp.	0	0	0	2	0	0	0	0	0
Hydracarina	35	27	76	1	5	1	3	0	7
Nematoda	9	6	4	8	5	6	2	0	3
Oligochaeta	5	6	16	8	7	9	4	0	16
Turbellaria									
Plariidae	0	0	0	0	0	2	0	0	0
Total number of taxa per station	46	37	43	24	31	33	25	22	27
Total number of organisms per station	379	279	746	84	160	365	72	77	136
Mean number of organisms per m²	27128	19970	53396	6012	11452	26126	5154	5511	9734

Appendix II. Table 2. Total fauna, number of taxa, and mean number of organisms/m^2 collected at each station in the Camden Study on 20 June 1994.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta	0	0	0	0	0	1	0	0	1
Coleoptera									
Elmidae	10	4	6	1	2	3	4	15	9
Ancyronyx varigatus	0	0	0	1	0	0	0	0	0
Optioservus spp.	0	0	0	0	9	0	0	0	0
Optioservus spp. adults	0	0	0	2	1	0	0	0	0
Oulimnius latiusculus	3	0	0	1	2	2	8	0	0
Stenelmis spp. adults	1	2	1	1	0	0	0	0	0
Psephenidae									
Psephenus herricki	4	142	48	1	0	1	1	0	1
Psephenus herricki adults	0	4	0	0	0	0	0	0	0
Ptilodactylidae									
Anchytarsus bicolor	4	3	5	1	8	0	0	0	0
Collembola									
Isotomidae	0	0	0	0	4	3	3	1	3
Diptera	2	0	2	0	1	0	0	1	4
Diptera adults	0	0	0	0	4	2	2	4	0
Diptera pupae	0	7	1	0	1	3	8	7	5
Ceratopogonidae	15	17	9	2	6	1	2	6	1
Atrichopogon spp.	0	0	0	0	0	1	0	0	0
Bezzia/Palpomyia gp.	0	0	0	1	2	6	24	2	3
Chaoboridae	0	0	0	0	0	1	0	0	0
Chironomidae	3	0	0	0	0	1	0	0	0
Ablabesmyia spp.	0	0	0	0	1	2	9	0	7
Chaetocladius spp.	8	0	0	0	0	0	0	0	0
Chironomini	0	0	0	0	0	0	3	10	0
Cladotanytarsus spp.	1	0	0	0	0	0	0	0	0
Corynoneura spp.	4	12	10	0	0	6	4	29	21
Cricotopus spp.	0	0	3	0	0	0	0	0	0
Cricotopus/Orthocladius	0	0	0	0	2	0	0	0	0
Demicryptochironomus cuneatus	14	22	4	0	0	0	0	0	0
Dicrotendipes spp.	0	0	0	0	0	0	2	0	0
Diplocladius cultriger	1	0	0	0	1	0	0	0	0
Harnischia spp.	0	0	0	0	0	0	2	0	0
Hydrobaenus pilipes gp.	0	0	0	1	0	0	0	0	0
Krenosmittia spp.	0	0	17	0	0	15	19	7	24
Larsia spp.	0	7	0	2	0	5	29	4	46
Micropsectra spp.	0	0	0	0	0	0	0	0	4
nocladius spp.	0	0	0	0	0	0	2	0	0
tarsia spp.	0	2	0	1	0	1	0	2	0
Nilotanypus spp.	0	34	0	0	0	5	13	6	25
Orthocladiie	1	0	2	0	0	0	0	0	0

Appendix II. Table 2. Continued…

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Parachaetocladius spp.	1	24	28	0	1	2	0	0	0
Paracricotopus spp.	0	0	0	0	0	1	0	0	0
Parakiefferiella spp.	0	0	0	0	0	0	0	2	10
Parakiefferiella triquetra	0	0	0	0	0	0	2	0	0
Paralauterborniella nigrohalteralis	0	0	0	0	0	0	3	2	0
Parameri spp.	0	0	1	0	1	3	0	0	0
Parametriocnemus spp.	17	10	0	6	2	14	26	22	20
Parasmittia spp.	1	0	0	0	0	0	0	0	0
Paratendipes spp.	0	0	0	0	0	2	2	0	0
Polypedilum (P.) convictum	7	10	13	1	0	2	0	0	12
Polypedilum (P.) fallax	4	0	9	1	2	0	0	0	0
Polypedilum (P.) illinoense	1	0	4	0	0	0	2	13	3
Polypedilum (T.) halterale	0	0	0	3	0	1	0	2	3
Polypedilum (T.) scalaenum gp.	5	0	12	3	1	3	10	6	4
Polypedilum spp.	1	0	0	0	0	0	0	0	0
Rheocricotopus spp.	0	0	0	0	0	0	0	3	0
Rheotanytarsus spp.	18	36	13	0	0	4	2	8	29
Robackia demeijerei	5	10	4	0	1	0	0	2	0
Stempelli spp.	1	0	2	0	0	0	0	0	0
Stempellinella spp.	0	0	0	2	0	6	13	4	10
Tanypodie	1	0	2	0	4	7	5	0	0
Tanytarsus spp.	90	557	59	1	0	22	43	20	41
Thienemannia spp.	1	0	0	0	1	0	2	2	0
Thienemanniella spp.	0	0	2	0	0	0	0	3	3
Thienemannimyia complex	0	0	13	1	0	16	12	5	26
Tribelos spp.	1	0	0	0	0	0	0	0	0
Tvetenia bavarica gp.	1	0	0	1	3	2	3	47	16
Zavrelimyia spp.	0	0	4	0	0	1	6	0	11
Culicidae									
Culex spp.	2	0	0	0	0	3	3	3	0
Empididae									
Hemerodromia spp.	3	0	3	0	2	1	0	2	5
Simuliidae									
Simulium spp.	0	1	0	0	1	1	0	7	4
Tanyderidae									
Protoplasa fitchii	1	0	0	0	1	0	0	0	0
Tipulidae	0	6	0	0	0	0	0	0	0
Hexatoma spp.	2	14	12	2	2	3	4	3	4
Pseudolimnophila spp.	9	8	1	3	1	11	0	1	1
Tipula spp.	0	0	0	0	1	0	0	0	1
Ephemeroptera	1	0	0	0	0	0	0	0	0
Baetidae									
Baetis spp.	3	24	7	9	6	31	20	47	123

Appendix II. Table 2. Continued…

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Ephemeroptera									
Caenidae									
Caenis spp.	2	11	1	27	2	3	11	0	0
Ephemeridae									
Hexagenia spp.	0	0	0	0	0	0	0	0	1
Heptageniidae									
Stenonema spp.	0	0	3	0	0	0	0	0	0
Leptophlebiidae									
Habrophlebiodes spp.	1	9	4	0	0	6	19	3	4
Hemiptera	0	0	0	1	0	0	0	0	0
Lepidoptera	0	0	0	0	1	0	0	0	0
Megaloptera									
Corydalidae									
Nigronia spp.	0	2	0	1	0	0	0	0	0
Odonata									
Aeshnidae									
Boyeria spp.	0	2	0	0	0	0	0	0	0
Calopterygidae									
Calopteryx spp.	0	0	0	1	0	0	0	2	0
Gomphidae	0	4	1	0	0	0	1	1	3
Plecoptera	13	9	4	1	3	1	0	1	3
Nemouridae									
Amphinemura spp.	0	0	0	0	0	0	0	1	0
Perlidae									
Eccoptura xanthenes	1	2	0	3	0	0	0	0	0
Trichoptera	0	3	4	25	17	8	17	10	53
Calamoceratidae									
Anisocentropus pyraloides	1	0	1	0	0	0	0	0	0
Glossosomatidae									
Glossosoma spp.	2	4	0	1	2	0	0	0	0
Hydropsychidae	4	4	0	1	0	0	31	0	0
Cheumatopsyche spp.	0	0	0	0	0	0	0	0	1
Diplectrona spp.	11	40	3	7	2	5	12	24	22
Hydropsyche spp.	0	0	0	0	0	0	0	2	0
Macrostemum carolina	0	0	0	0	0	0	0	1	0
Macrostemum spp.	0	0	0	0	1	0	0	0	0
Limnephilidae									
Neophylax spp.	0	0	0	0	0	0	0	1	0
Molannidae	0	2	0	0	0	0	0	0	0
Philopotamidae									
Chimarra spp.	0	4	0	0	0	0	0	0	0
OTHER AQUATIC INVERTEBRATES									
Amphipoda									
Gammaridae	0	2	0	2	0	0	0	0	0

Appendix II. Table 2. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Copepoda	0	0	1	0	0	1	0	1	0
Calanoida	0	0	0	3	0	0	12	1	2
Harpacticoida	5	0	0	0	1	2	3	1	0
Decapoda									
Cambaridae	0	0	1	0	0	0	0	0	0
Gastropoda	0	0	5	8	20	0	1	0	0
Pleuroceridae									
Elimia spp.	0	1	0	10	0	0	1	0	0
Hydracarina	2	127	20	3	9	11	19	2	8
Nematoda	7	14	4	3	15	0	5	3	11
Oligochaeta	63	17	13	38	41	27	20	15	19
Lumbriculidae	6	0	0	0	0	0	0	1	0
Ostracoda	0	0	0	1	0	0	5	0	0
Pelecypoda	2	0	0	0	0	0	0	0	0
Turbellaria									
Planariidae	14	18	6	0	0	3	0	0	0
Total number of taxa per station	52	42	45	42	42	49	48	51	44
Total number of organisms per station	381	1231	368	184	188	262	450	368	607
Mean number of organisms per m²	27271	88111	26340	13170	13456	18753	32210	26340	43447

Appendix II. Table 3. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 14 September 1994.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta		0	0	0	0	0	1	0	0
Coleoptera		0	0	0	1	0	0	0	0
Elmidae		0	16	7	6	6	0	0	4
Optioservus spp.		0	0	0	6	0	0	0	0
Oulimnius latiusculus		0	0	0	0	2	3	0	1
Stenelmis spp. adults		1	2	0	1	0	1	0	4
Psephenidae									
Psephenus herricki		15	42	1	2	116	36	3	27
Ptilodactylidae									
Anchytarsus bicolor		5	9	4	21	0	2	0	0
Collembola		1	0	1	0	0	0	0	0
Isotomidae		0	0	0	0	2	10	0	0
Sminthuridae		0	0	0	1	0	0	0	0
Diptera		6	3	0	2	0	0	1	4
Diptera adults		0	3	2	0	0	4	1	4
Diptera pupae		2	7	0	0	3	2	6	7
Ceratopogonidae		3	6	0	0	0	4	1	1
Bezzia/Palpomyia gp.		48	38	0	2	32	32	2	17
Chironomidae		0	0	0	0	0	2	1	4
Chironomie		0	0	0	6	0	0	0	0
Chironomini		0	0	1	0	0	1	0	0
Corynoneura spp.		78	122	0	0	18	4	18	7
Cricotopus/Orthocladius		0	0	0	1	0	0	0	0
Demicryptochironomus cuneatus		13	12	0	0	0	0	0	0
Diplocladius cultriger		0	12	0	0	0	2	0	0
Krenopelopia spp.		12	8	0	0	0	4	2	31
Krenosmittia spp.		2	0	0	0	22	11	0	0
Larsia spp.		4	20	0	0	13	11	1	8
Micropsectra spp.		0	0	0	0	0	2	0	0
tarsia spp.		2	0	0	0	0	0	0	0
Nilotanypus spp.		0	28	1	0	21	7	34	29
Nilothauma spp.		2	0	0	0	0	0	0	0
Parachaetocladius spp.		0	24	0	0	8	1	0	0
Parakiefferiella triquetra		0	0	0	0	0	2	0	0
Parametriocnemus spp.		2	0	1	0	2	3	0	3
Paratanytarsus spp.		0	0	0	0	3	0	0	0
Polypedilum (P.) convictum		12	59	2	0	25	1	0	0
Polypedilum (P.) fallax		2	0	0	0	0	0	0	0
Polypedilum (P.) illinoense		0	0	0	0	3	2	0	0
Polypedilum (T.) halterale		0	0	5	1	0	0	0	3
Polypedilum (T.) scalaenum gp.		2	20	8	0	7	3	7	19
Polypedilum spp.		0	0	0	0	0	0	0	3
Psilometriocnemus spp.		2	0	0	0	0	0	0	0

Appendix II. Table 3. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Rheotanytarsus spp.		210	131	14	15	73	17	79	61
Robackia demeijerei		0	0	0	0	0	0	42	0
Stempelli spp.		5	0	0	0	0	1	0	0
Stempellinella spp.		0	0	0	0	0	25	10	33
Sublettea coffmanni		0	0	0	0	0	0	0	4
Tanypodie		0	0	0	0	0	1	0	0
Tanypodie pupae		2	0	0	0	0	0	0	0
Tanytarsus spp.		418	718	1	3	20	21	23	59
Thienemanniella spp.		14	0	1	1	7	0	9	3
Thienemannimyia complex		0	32	0	0	2	1	4	0
Tvetenia bavarica gp.		0	0	21	15	3	0	0	0
Culicidae		0	0	0	0	1	1	0	1
Empididae									
Hemerodromia spp.		0	1	0	2	2	0	0	0
Psychodidae									
Pericoma/Telmatoscopus		1	0	0	0	0	0	0	0
Simuliidae		0	0	0	2	0	0	0	0
Simulium spp.		3	4	0	3	0	0	2	4
Tipulidae		0	5	0	0	0	0	0	0
Hexatoma spp.		10	15	1	0	6	16	3	21
Ephemeroptera									
Baetidae									
Baetis spp.		42	35	16	23	90	34	51	107
Caenidae									
Caenis spp.		6	0	14	7	0	4	0	0
Ephemeridae									
Hexagenia spp.		0	0	0	0	8	2	0	0
Heptageniidae									
Stenonema spp.		0	7	0	0	0	0	0	4
Leptophlebiidae									
Habrophlebiodes spp.		2	12	0	0	51	42	7	24
Odonata									
Aeshnidae									
Boyeria spp.		1	0	0	0	0	0	0	0
Cordulegastridae									
Cordulegaster spp.		0	0	0	0	0	0	1	0
Gomphidae		0	2	0	1	0	0	1	0
Erpetogomphus desigtus		0	0	1	0	0	0	0	0
Odonata		0	0	0	0	0	1	0	0
Plecoptera		12	19	3	40	10	4	1	25

Appendix II. Table 3. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Trichoptera		2	0	13	7	16	6	5	12
Glossosomatidae									
Glossosoma spp.		0	0	0	1	0	0	0	1
Hydropsychidae									
Cheumatopsyche spp.		0	0	0	4	0	32	0	1
Diplectrona spp.		0	6	26	16	11	12	4	6
Hydropsyche spp.		0	0	0	1	0	0	0	9
Molannidae									
Molanna spp.		0	0	1	0	0	0	0	0
Philopotamidae									
Chimarra spp.		0	6	2	0	0	0	0	0
OTHER AQUATIC INVERTEBRATES									
Amphipoda									
Gammaridae		1	0	0	0	0	0	0	0
Copepoda		1	0	1	0	2	21	0	0
Gastropoda		0	8	1	0	2	10	0	0
Pleuroceridae									
Elimia spp.		0	0	8	0	2	3	0	0
Hydracarina		184	200	0	12	40	55	14	79
Nematoda		34	11	6	41	2	7	8	18
Oligochaeta		0	5	8	15	2	0	0	12
Ostracoda		1	0	0	0	0	2	0	0
Pelecypoda		0	0	1	0	0	0	0	0
Turbellaria									
Planariidae		1	3	0	0	0	0	0	0
Total number of taxa per station		40	37	30	31	36	48	29	38
Total number of organisms per station		1164	1651	172	259	633	469	341	660
Mean number of organisms per m^2		83315	118173	12311	18538	45308	33570	24408	47241

Appendix II. Table 4. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 20 February 1995.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Coleoptera									
Elmidae	8	1	2	0	0	0	0	0	0
Dubiraphia spp.	0	0	0	0	0	0	0	1	1
Optioservus spp.	0	0	3	0	23	0	1	0	0
Oulimnius latiusculus	0	0	2	1	1	4	2	0	2
Oulimnius latiusculus adults	2	0	0	0	0	0	0	0	0
Stenelmis spp. adults	0	0	0	1	0	0	0	0	0
Psephenidae									
Psephenus herricki	1	0	34	2	0	19	20	0	4
Ptilodactylidae									
Anchytarsus bicolor	1	0	0	0	1	0	0	0	0
Diptera	1	0	0	0	0	2	2	0	0
Diptera adults	0	0	2	0	0	0	1	1	0
Diptera pupae	2	1	4	1	0	0	0	0	0
Ceratopogonidae	0	7	0	0	4	6	1	44	1
Bezzia/Palpomyia gp.	9	24	22	3	3	90	16	1	21
Chironomidae	1	0	0	0	0	0	7	0	0
Cladotanytarsus spp.	0	5	0	0	0	0	0	0	0
Corynoneura spp.	8	4	61	0	0	1	3	0	2
Cricotopus spp.	0	0	5	0	0	0	0	0	0
Cricotopus/Orthocladius	2	0	2	1	1	0	2	0	0
Cryptochironomus spp.	0	0	0	1	0	0	0	0	0
Diplocladius cultriger	1	0	0	0	0	0	0	0	0
Eukiefferiella claripennis gp.	0	0	0	0	1	0	0	0	0
Harnischia spp.	0	5	0	0	0	0	0	0	0
Krenosmittia spp.	0	5	0	0	0	3	0	0	0
Larsia spp.	0	0	0	0	0	0	0	1	2
Micropsectra spp.	0	0	1	0	0	0	0	0	0
Monopelopia spp.	0	0	0	0	0	3	4	0	10
nocladius spp.	0	0	0	0	0	0	2	0	0
Nilotanypus spp.	3	0	0	1	0	1	21	5	13
Nimbocera pinderi	0	5	0	0	0	0	0	0	0
Orthocladiie	0	0	0	0	1	0	0	0	0
Parachaetocladius spp.	1	0	1	0	1	1	0	0	0
Parachironomus spp.	1	0	0	0	0	0	0	0	0
Parakiefferiella triquetra	1	0	0	0	0	0	0	0	0
Parameri spp.	1	0	0	0	0	0	0	0	0
Parametriocnemus spp.	3	2	24	2	0	4	28	7	12
Polypedilum (P.) convictum	3	4	15	0	1	1	7	0	0
Polypedilum (P.) illinoense	0	0	5	0	0	0	0	1	0
Polypedilum (T.) halterale	0	0	13	0	3	0	0	17	1
Polypedilum (T.) scalaenum gp.	2	5	2	0	2	11	8	9	6
Rheotanytarsus spp.	21	9	6	0	3	1	23	23	47

Appendix II. Table 4. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Robackia demeijerei	0	1	0	0	0	0	0	1	0
Stempelli spp.	0	54	0	0	0	0	0	0	0
Stempellinella spp.	2	0	0	0	0	10	11	0	5
Tanypodie	0	0	0	0	0	0	0	0	1
Tanytarsus spp.	66	89	378	2	1	4	10	6	4
Thienemanniella spp.	7	5	10	8	6	1	6	2	1
Thienemannimyia complex	0	0	0	0	0	0	4	0	4
Tvetenia bavarica gp.	9	1	25	10	8	1	11	6	6
Culicidae	0	0	0	0	0	0	0	1	0
Empididae									
Hemerodromia spp.	0	0	2	0	8	0	0	0	0
Simuliidae									
Simulium spp.	41	7	18	2	3	0	1	2	3
Tipulidae	1	1	0	0	0	0	0	0	0
Hexatoma spp.	2	18	8	0	1	5	0	3	2
Pseudolimnophila spp.	1	1	0	0	0	0	1	0	2
Tipula spp.	0	0	0	0	0	0	0	1	1
Ephemeroptera									
Baetidae									
Baetis spp.	12	2	2	18	3	0	0	4	8
Caenidae									
Caenis spp.	0	0	0	1	3	1	5	0	0
Ephemeridae									
Hexagenia spp.	0	1	0	0	0	0	0	0	0
Leptophlebiidae									
Habrophlebia vibrans	0	0	0	0	0	2	0	0	0
Habrophlebiodes spp.	0	0	7	1	0	0	24	1	1
Hemiptera	0	1	0	0	0	0	0	0	0
Odonata									
Cordulegastridae									
Cordulegaster spp.	0	0	0	0	0	0	0	0	1
Plecoptera	2	0	0	0	0	2	3	9	27
Chloroperlidae									
Alloperla spp.	19	13	32	2	0	7	9	2	4
Nemouridae									
Amphinemura spp.	6	1	0	0	0	0	0	6	1
Perlidae									
Eccoptura xanthenes	0	0	0	0	1	0	0	0	0

Appendix II. Table 4. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Trichoptera	0	0	2	5	2	0	0	0	0
Glossosomatidae									
Glossosoma spp.	3	0	2	9	20	0	0	0	0
Hydropsychidae	0	0	2	0	0	0	1	0	3
Cheumatopsyche spp.	0	0	0	0	0	1	6	0	2
Diplectrona spp.	0	0	2	2	2	0	0	0	0
Hydropsyche spp.	0	0	0	1	1	0	0	0	1
Copepoda	5	1	0	0	0	0	0	0	0
Gastropoda	0	0	1	0	0	1	10	1	0
Pleuroceridae									
Elimia spp.	0	0	0	2	0	2	4	0	0
Hydracarina	0	0	2	1	1	0	5	0	2
Nematoda	4	3	3	4	2	5	1	2	0
Oligochaeta	51	13	21	10	15	73	10	2	84
Pelecypoda								0	0
Corbiculidae									
Corbicula fluminea	0	1	0	0	0	0	0		
Turbellaria								0	0
Planariidae	3	1	4	0	0	0	0		
Total number of taxa per station	37	32	36	25	29	28	35	27	34
Total number of organisms per station	306	291	725	91	122	262	270	159	285
Mean number of organisms per m²	21903	20829	51893	6513	8732	18753	19326	11381	20399

Appendix II. Table 5. Total fauna, number of taxa, and mean number of organisms/m^2 collected at each station in the Camden Study on 13 June 1995.

AQUATIC INSECTS	1 C	2A	2B	3A	3B	4A	4B	5A	5B
Coleoptera									
Dryopidae									
Helichus spp. adults		0	1	0	0	0	0	0	0
Elmidae		10	4	0	4	37	2	27	10
Ancyronyx varigatus		0	0	0	0	2	0	0	0
Elmidae adults		0	0	0	0	0	0	1	0
Optioservus spp.		0	1	0	2	0	0	0	0
Optioservus spp. adults		1	0	0	1	0	0	0	0
Psephenidae									
Psephenus herricki		21	29	0	0	151	17	28	0
Psephenus herricki adults		1	0	0	0	0	0	0	0
Ptilodactylidae									
Anchytarsus bicolor		1	0	1	0	0	0	1	1
Collembola		0	0	0	0	0	0	1	0
Isotomidae		0	0	0	0	1	0	0	0
Sminthuridae		0	0	0	0	0	0	1	0
Diptera		3	0	0	0	0	2	7	20
Diptera adults		0	1	2	0	1	1	2	1
Diptera pupae		9	9	1	0	10	2	5	4
Ceratopogonidae		21	55	0	2	18	49	26	13
Bezzia/Palpomyia gp.		6	0	5	0	0	0	0	15
Chironomidae		0	7	0	1	0	0	0	3
Ablabesmyia spp.		0	0	0	0	9	0	0	0
Chironomini		0	4	2	1	5	0	3	0
Corynoneura spp.		95	68	0	0	0	11	6	32
Cricotopus bicinctus		0	0	0	0	10	0	0	0
Cricotopus/Orthocladius		8	0	0	0	0	0	0	0
Cryptochironomus spp.		0	0	2	0	0	0	0	0
Demicryptochironomus cuneatus		18	38	0	0	0	0	0	0
Djalmabatista spp.		0	0	0	1	0	0	0	0
Glyptotendipes spp.		0	0	0	0	0	0	3	0
Heterotrissocladius macidus gp.		9	0	0	0	0	0	0	0
Krenosmittia spp.		0	0	0	0	0	4	11	7
Larsia spp.		37	24	0	1	37	10	12	30
Micropsectra spp.		0	0	0	1	0	0	0	0
Monopelopia spp.		0	4	0	0	0	0	0	0
Nilotanypus spp.		16	8	0	0	0	6	42	28
Parachaetocladius spp.		0	70	3	1	0	3	0	0
Parameri spp.		0	0	0	0	0	0	3	0
Parametriocnemus spp.		28	0	1	1	19	0	5	7
Paratendipes spp.		0	0	0	0	10	0	3	0
Polypedilum (P.) convictum		50	0	0	0	38	2	4	3
Polypedilum (P.) illinoense		0	0	0	1	0	0	0	0

Appendix II. Table 5. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Polypedilum (T.) halterale		4	17	1	1	0	0	0	0
Polypedilum (T.) scalaenum gp.		0	17	1	1	5	1	8	1
Potthastia longima gp.		0	0	0	1	0	0	0	0
Pseudorthocladius spp.		0	8	0	0	0	0	0	0
Rheocricotopus spp.		8	0	0	0	0	0	0	0
Rheotanytarsus spp.		89	77	0	2	19	4	29	40
Saetheria spp.		0	0	0	0	9	0	0	0
Stempellinella spp.		0	4	0	0	0	0	0	4
Tanypodie		8	0	0	0	0	2	0	3
Tanytarsus spp.		198	175	11	2	426	25	82	47
Thienemanniella spp.		25	0	3	0	110	0	0	3
Thienemannimyia complex		29	7	0	0	15	10	27	16
Tvetenia bavarica gp.		0	0	0	3	0	0	0	0
Zavrelimyia spp.		0	0	0	0	0	0	0	3
Culicidae									
Culex spp.		0	0	1	0	7	0	0	2
Empididae									
Hemerodromia spp.		0	0	0	0	8	0	1	2
Simuliidae									
Simulium spp.		18	0	2	13	0	0	0	2
Tipulidae		15	14	2	0	19	12	14	5
Pseudolimnophila spp.		17	3	0	0	0	0	1	7
Ephemeroptera									
Baetidae		13	0	0	0	0	0	0	0
Baetis spp.		118	20	8	8	123	22	40	31
Caenidae									
Caenis spp.		21	23	1	10	3	3	0	0
Heptageniidae									
Stenonema spp.		2	1	0	0	2	1	0	1
Leptophlebiidae									
Habrophlebiodes spp.		5	18	0	0	35	49	26	23
Odonata									
Calopterygidae									
Calopteryx spp.		0	1	0	0	0	1	0	0
Gomphidae		0	1	0	0	1	0	0	0
Erpetogomphus desigtus		1	1	0	0	0	0	0	0
Plecoptera		6	10	1	0	0	3	1	0
Nemouridae									
Amphinemura spp.		4	0	0	0	0	0	0	0
Perlidae									
Acroneuria spp.		1	0	0	0	0	0	0	0

Appendix II. Table 5. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Trichoptera		0	0	1	9	6	1	2	2
Glossosomatidae									
Glossosoma spp.		0	0	8	6	0	0	1	1
Hydropsychidae		0	2	0	13	10	0	0	0
Cheumatopsyche spp.		3	10	0	0	0	0	0	0
Diplectrona spp.		21	10	6	11	34	12	10	37
Hydropsyche spp.		4	0	0	0	0	0	0	2
Macrostemum carolina		3	0	1	0	0	0	0	0
Limnephilidae		0	0	0	0	0	0	0	1
Philopotamidae									
Chimarra spp.		1	0	0	0	0	0	0	0
OTHER AQUATIC INVERTEBRATES		948	742	64	97	1180	255	433	407
Amphipoda									
Gammaridae		2	0	0	1	0	0	0	0
Copepoda		0	2	0	0	40	4	4	0
Decapoda		0	0	0	0	2	0	0	0
Gastropoda		6	8	0	5	28	4	0	0
Pleuroceridae									
Elimia spp.		0	0	7	17	0	8	0	0
Hydracarina		135	138	0	3	34	30	7	27
Nematoda		0	5	4	0	2	0	1	4
Oligochaeta		10	15	22	6	14	8	8	3
Ostracoda		1	0	0	0	16	0	3	0
Total number of taxa per station		46	40	25	30	38	31	38	38
Total number of organisms per station		1102	910	97	129	1316	309	456	441
Mean number of organisms per m²		78878	65135	6946	9233	94195	22117	32639	31565

Appendix II. Table 6. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 16 August 1995.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta		0	0	0	0	2	0	0	0
Coleoptera		0	0	0	0	6	0	0	0
Elmidae		9	1	1	9	2	7	1	4
Ancyronyx varigatus		0	0	0	0	0	0	0	3
Macronychus glabratus		0	0	0	0	0	0	1	0
Optioservus spp.		0	0	0	5	0	0	0	0
Stenelmis spp. adults		0	2	0	0	0	0	0	0
Psephenidae									
Psephenus herricki		131	34	0	3	84	1	2	3
Ptilodactylidae									
Anchytarsus bicolor		0	23	2	12	0	1	0	0
Collembola		0	4	0	0	0	0	0	0
Isotomidae		0	0	1	0	0	0	0	0
Sminthuridae		2	0	0	0	3	0	0	0
Diptera		0	0	1	0	0	2	4	2
Diptera adults		3	0	0	0	1	0	0	0
Diptera pupae		18	7	2	1	4	7	4	5
Ceratopogonidae		3	2	7	7	6	8	9	5
Bezzia/Palpomyia gp.		36	60	8	1	10	32	6	6
Chironomidae		0	2	0	0	0	1	2	4
Ablabesmyia spp.		0	0	0	1	3	0	0	0
Chironomini		5	4	0	0	0	0	0	0
Cladotanytarsus spp.		0	0	0	0	24	0	0	0
Corynoneura spp.		1	18	0	0	0	3	3	5
Cricotopus bicinctus		6	0	0	0	14	0	0	0
Cricotopus spp.		5	0	0	0	0	0	0	0
Cryptochironomus spp.		5	0	0	0	0	0	0	0
Cryptotendipes spp.		0	0	0	0	3	0	0	0
Demicryptochironomus cuneatus		64	8	0	0	0	0	0	0
Dicrotendipes spp.		0	0	0	0	27	0	0	0
Djalmabatista spp.		0	0	0	0	3	0	0	0
Krenopelopia spp.		1	0	0	0	0	0	2	3
Krenosmittia spp.		12	2	0	0	0	32	4	13
Larsia spp.		29	8	0	0	35	0	1	0
Microtendipes pedellus gp.		0	0	0	0	4	0	0	0
Monopelopia spp.		8	25	0	1	10	8	6	3
nocladius spp.		5	0	0	0	0	0	0	0
tarsia spp.		12	5	0	0	0	0	0	0
Nilotanypus spp.		6	13	0	1	0	4	8	7
Orthocladiie		0	0	0	0	0	0	1	0
Parachaetocladius spp.		17	0	0	0	0	1	0	0
Paralauterborniella nigrohalteralis		0	0	1	0	0	0	0	0
Parametriocnemus spp.		0	0	0	0	0	1	0	0

Appendix II. Table 6. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Diptera									
Chironomidae									
Polypedilum (P.) convictum		14	5	0	0	55	8	1	0
Polypedilum (P.) illinoense		0	0	0	0	3	0	0	0
Polypedilum (T.) halterale		12	9	11	0	3	1	0	0
Polypedilum (T.) scalaenum gp.		0	0	7	0	11	7	1	1
Procladius spp.		0	0	0	0	3	0	0	0
Rheotanytarsus spp.		2	22	2	1	0	1	2	6
Robackia demeijerei		0	0	0	1	0	0	0	0
Stempellinella spp.		1	0	0	0	3	0	1	1
Tanytarsini		0	0	0	0	0	0	1	0
Tanytarsus spp.		37	186	2	0	80	5	2	3
Thienemanniella spp.		276	10	2	1	28	1	0	0
Thienemannimyia complex		25	6	0	0	0	1	2	0
Tvetenia bavarica gp.		0	0	2	2	0	0	0	0
Culicidae		0	0	0	0	2	0	1	0
Dixidae									
Dixa spp.		0	0	0	1	0	0	0	0
Empididae									
Hemerodromia spp.		0	0	1	1	0	0	0	0
Simuliidae									
Simulium spp.		0	0	1	3	0	0	0	0
Tipulidae									
Hexatoma spp.		20	17	1	0	12	7	8	4
Pseudolimnophila spp.		0	0	0	0	0	0	1	4
Tipula spp.		0	5	0	0	0	0	0	0
Ephemeroptera		1	0	0	0	0	0	0	0
Baetidae		0	0	0	0	0	0	0	1
Baetis spp.		97	120	16	13	43	6	65	41
Caenidae									
Caenis spp.		1	4	5	2	55	1	1	0
Heptageniidae									
Stenonema spp.		1	6	0	0	0	0	0	0
Leptophlebiidae									
Habrophlebiodes spp.		13	46	0	0	0	23	21	11
Hemiptera									
Mesoveliidae									
Mesovelia spp.		0	0	0	0	0	1	0	0
Veliidae		0	4	0	0	0	0	0	0
Lepidoptera		0	0	0	0	0	0	1	0
Odonata									
Gomphidae		0	0	0	0	0	0	1	0
Erpetogomphus desigtus		0	3	0	0	0	0	0	0
Stylogomphus albistylus		0	1	0	0	0	0	0	0

Appendix II. Table 6. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Plecoptera		4	0	0	2	8	0	0	0
Perlidae		0	0	0	0	0	0	0	1
Eccoptura xanthenes		0	0	0	0	0	1	0	0
Trichoptera		0	9	0	2	0	0	1	0
Glossosomatidae									
Glossosoma spp.		0	0	1	3	0	0	0	0
Hydropsychidae		3	0	0	0	0	1	0	0
Cheumatopsyche spp.		0	0	0	0	0	3	0	3
Diplectrona spp.		1	9	1	14	8	8	4	5
Hydropsyche spp.		0	1	0	0	4	0	0	0
Macrostemum carolina		0	0	0	0	0	0	0	1
Hydroptilidae		1	0	0	0	2	0	0	0
OTHER AQUATIC INVERTEBRATES									
Copepoda		0	0	1	2	38	0	0	0
Calanoida		4	0	0	0	8	0	0	2
Gastropoda		0	10	0	0	10	1	0	0
Pleuroceridae									
Elimia spp.		0	0	9	0	0	2	0	0
Hydracarina		136	346	0	5	18	16	5	25
Nematoda		12	18	4	0	0	0	2	1
Oligochaeta		108	0	22	11	14	48	6	22
Ostracoda		4	0	2	0	25	0	1	1
Turbellaria		1	34	0	0	0	0	0	0
Total number of taxa per station		44	39	26	26	40	34	35	31
Total number of organisms per station		1152	1089	113	105	674	250	181	196
Mean number of organisms per m²		82457	77947	8088	7516	48243	17894	12955	14029

Appendix II. Table 7. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 12 October 1995.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta	2	0	0	0	0	1	0	1	0
Coleoptera									
Elmidae	4	3	6	0	2	3	1	1	2
Ancyronyx varigatus	0	0	0	0	6	2	0	0	0
Macronychus glabratus	0	0	0	0	0	0	0	1	0
Oulimnius latiusculus	0	0	0	0	0	3	3	0	0
Promoresia spp.	0	0	0	0	0	0	5	0	0
Psephenidae									
Psephenus herricki	0	11	19	1	0	7	12	2	0
Ptilodactylidae									
Anchytarsus bicolor	0	0	2	0	3	0	0	0	0
Diptera	3	0	0	0	1	0	1	1	2
Diptera adults	0	0	0	0	0	0	0	0	1
Diptera pupae	3	0	0	0	3	0	1	0	1
Ceratopogonidae	17	4	4	3	20	5	0	7	8
Bezzia/Palpomyia gp.	15	2	16	1	0	17	16	11	4
Chironomidae	0	1	0	0	0	1	0	0	1
Chironomini	0	0	0	0	0	0	1	1	1
Cladotanytarsus spp.	0	2	0	0	0	3	0	0	0
Corynoneura spp.	7	2	2	1	4	1	2	0	5
Cricotopus bicinctus	0	11	0	0	0	4	0	0	0
Demicryptochironomus cuneatus	0	1	4	0	0	0	0	0	0
Diplocladius cultriger	0	0	0	0	0	0	1	0	0
Krenopelopia spp.	0	0	0	0	0	0	1	0	0
Krenosmittia spp.	5	0	1	0	0	1	10	10	7
Labrundinia spp.	0	0	0	0	0	0	0	0	1
Larsia spp.	0	0	3	0	0	0	1	0	0
Monopelopia spp.	0	4	5	0	0	1	3	0	1
Nilotanypus spp.	3	0	2	0	1	0	2	1	3
Orthocladiie	0	1	0	0	0	0	0	0	0
Parachaetocladius spp.	0	0	1	0	0	0	0	0	0
Parameri spp.	0	0	0	0	0	0	0	5	0
Parametriocnemus spp.	0	0	0	0	0	0	1	0	0
Paratendipes spp.	0	0	0	0	0	1	1	1	0
Polypedilum (P.) convictum	0	23	11	0	0	10	18	0	0
Polypedilum (T.) halterale	0	0	0	7	2	1	2	1	0
Polypedilum (T.) scalaenum gp.	0	0	0	2	0	0	0	2	0
Rheotanytarsus spp.	11	4	3	2	3	1	2	6	9
Robackia demeijerei	0	0	0	0	0	0	0	0	1
Tanytarsus spp.	1	2	1	0	0	15	42	4	3
Thienemanniella spp.	0	4	0	9	7	3	0	0	0
Thienemannimyia complex	0	0	0	0	0	0	0	1	0
Tvetenia bavarica gp.	0	0	0	2	4	0	0	0	0

Appendix II. Table 7. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Simuliidae	0	0	0	0	1	0	0	0	0
Simulium spp.	0	1	0	0	0	0	0	0	0
Tanyderidae	0	0	0	1	0	0	0	0	0
Tipulidae	0	1	0	0	0	0	4	0	0
Hexatoma spp.	3	5	6	1	2	0	4	8	3
Pseudolimnophila spp.	0	0	0	0	0	0	0	1	0
Ephemeroptera	0	1	1	0	0	1	0	0	0
Baetidae									
Baetis spp.	11	31	75	5	21	4	12	24	16
Caenidae									
Caenis spp.	1	2	1	1	16	83	9	0	0
Heptageniidae									
Stenonema spp.	0	0	1	0	0	0	0	0	0
Leptophlebiidae									
Habrophlebiodes spp.	1	6	4	0	0	3	4	10	1
Hemiptera									
Veliidae									
Rhagovelia spp.	0	0	0	0	1	0	0	0	0
Lepidoptera	1	0	0	0	0	0	0	0	0
Odonata									
Gomphidae									
Erpetogomphus desigtus	0	1	0	0	0	0	0	0	0
Stylogomphus albistylus	1	0	0	0	0	0	0	0	0
Plecoptera	13	3	1	0	0	0	3	0	3
Perlidae									
Eccoptura xanthenes	0	0	1	0	0	0	0	0	0
Trichoptera	0	0	0	1	0	5	0	2	0
Hydropsychidae	0	0	1	4	0	3	25	0	0
Cheumatopsyche spp.	0	2	0	0	0	1	0	0	0
Diplectrona spp.	0	6	7	2	5	0	0	0	0
Hydropsyche spp.	0	4	4	1	3	0	3	0	0
Macrostemum spp.	0	0	0	0	3	0	1	0	0
OTHER AQUATIC INVERTEBRATES									
Copepoda	0	0	0	0	1	0	0	1	0
Harpacticoida	0	0	0	0	0	0	0	1	0
Gastropoda	0	5	1	0	0	2	0	0	1
Pleuroceridae									
Elimia spp.	0	0	0	1	1	9	3	0	1

Appendix II. Table 7. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Hydracarina	25	52	74	0	4	10	19	1	4
Nematoda	8	5	4	3	1	1	4	4	1
Oligochaeta	10	23	11	20	11	36	30	3	10
Pelecypoda									
Corbiculidae									
Corbicula fluminea	0	0	1	0	0	0	0	1	0
Turbellaria									
Planariidae	2	17	23	0	0	1	0	0	0
Total number of taxa per station	22	32	32	20	25	32	34	28	25
Total number of organisms per station	147	240	296	68	126	239	247	112	90
Mean number of organisms per m²	10522	17178	21187	4867	9019	17107	17679	8017	6442

Appendix II. Table 8. Total fauna, number of taxa, and mean number of organisms/m² collected at each station in the Camden Study on 11 December 1995.

AQUATIC INSECTS	1C	2A	2B	3A	3B	4A	4B	5A	5B
Insecta	0	2	0	0	0	0	0	0	0
Coleoptera									
Elmidae	0	0	0	0	0	4	0	0	0
Ancyronyx varigatus	0	0	0	1	0	0	0	0	0
Dubiraphia spp.	0	0	0	0	0	1	0	0	0
Optioservus spp.	0	1	2	2	1	0	0	0	0
Oulimnius latiusculus	2	3	1	3	0	5	0	0	0
Stenelmis spp. adults	0	1	0	0	1	0	0	0	0
Psephenidae									
Psephenus herricki	0	6	5	3	0	5	0	0	0
Ptilodactylidae									
Anchytarsus bicolor	0	0	1	5	0	0	0	0	0
Collembola	14	0	0	0	0	0	0	0	0
Diptera	2	2	0	0	1	5	2	1	0
Diptera adults	0	0	0	1	0	0	0	1	0
Diptera pupae	0	1	0	1	1	0	0	0	0
Ceratopogonidae	1	0	0	5	4	0	1	9	2
Bezzia/Palpomyia gp.	3	20	15	5	0	43	0	7	5
Chironomidae									
Chironomini	0	0	0	0	0	0	0	1	0
Cladotanytarsus spp.	0	0	0	0	0	3	0	0	0
Corynoneura spp.	14	9	1	5	6	0	1	2	3
Cricotopus bicinctus	0	4	1	0	1	1	0	0	0
Cricotopus tremulus gp.	0	2	0	0	0	0	0	0	0
Cryptochironomus spp.	0	2	1	0	0	0	0	1	0
Demicryptochironomus cuneatus	0	23	3	0	0	0	0	0	0
Eukiefferiella claripennis gp.	1	0	0	1	0	1	0	1	0
Krenosmittia spp.	0	0	0	4	0	5	1	2	1
Larsia spp.	0	7	2	1	0	3	0	2	6
Micropsectra spp.	0	0	0	0	0	2	0	0	0
Orthocladiie	0	1	0	0	0	1	0	0	0
Parametriocnemus spp.	1	0	0	0	0	1	0	1	0
Paratendipes spp.	0	0	1	0	0	0	1	0	1
Polypedilum (P.) convictum	3	31	4	2	0	1	1	1	2
Polypedilum (T.) halterale	0	0	1	14	0	0	0	25	0
Polypedilum (T.) scalaenum gp.	0	1	0	12	0	51	5	11	10
Polypedilum spp.	0	0	0	0	0	0	0	0	1
Pseudorthocladius spp.	0	0	0	0	1	0	0	0	0
Rheocricotopus spp.	0	2	0	0	0	0	0	1	0
Rheotanytarsus spp.	0	1	2	5	0	13	0	2	4
Tanypodie	0	0	2	0	0	0	0	0	0
Tanytarsus spp.	2	7	1	2	0	6	2	0	2
Thienemanniella spp.	0	4	2	9	5	33	3	1	3

Appendix II. Table 8. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Chironomidae									
Thienemannimyia complex	1	2	0	0	0	0	0	0	0
Tvetenia bavarica gp.	2	2	0	9	7	7	0	1	0
Empididae									
Hemerodromia spp.	0	1	0	1	1	0	0	0	0
Simuliidae									
Simulium spp.	15	18	10	1	18	30	1	0	1
Tipulidae	0	0	2	0	0	0	0	0	0
Hexatoma spp.	0	1	3	1	0	5	1	3	1
Pseudolimnophila spp.	0	0	0	0	0	1	0	0	0
Tipula spp.	2	0	0	0	1	0	0	0	0
Ephemeroptera	0	0	1	0	0	0	0	0	0
Baetidae	0	0	0	0	0	0	1	0	0
Baetis spp.	2	64	24	21	10	12	4	20	12
Caenidae									
Caenis spp.	0	0	0	0	0	18	3	0	0
Leptophlebiidae									
Habrophlebiodes spp.	0	5	0	1	0	0	0	0	2
Odonata									
Gomphidae	0	0	0	1	0	0	0	0	0
Progomphus spp.	0	0	0	0	0	2	0	0	0
Plecoptera	21	9	6	3	0	19	0	2	10
Chloroperlidae									
Alloperla spp.	21	9	8	0	0	0	0	0	0
Leuctridae	1	0	0	0	0	0	0	0	0
Nemouridae	0	0	0	0	0	1	0	0	0
Amphinemura spp.	3	0	0	0	0	0	0	0	0
Trichoptera	0	3	1	3	0	2	0	0	1
Glossosomatidae									
Glossosoma spp.	0	0	0	0	1	0	0	0	0
Hydropsychidae	0	0	0	0	0	0	0	2	2
Cheumatopsyche spp.	0	7	0	0	0	3	0	1	0
Diplectrona spp.	6	0	0	0	0	0	0	0	0
Hydropsyche spp.	0	28	7	4	7	2	0	0	0
Hydroptilidae									
Hydroptila spp.	0	0	0	0	0	3	0	0	0
Philopotamidae									
Chimarra spp.	0	2	0	0	0	0	0	0	0

Appendix II. Table 8. Continued…

OTHER AQUATIC INVERTEBRATES	1C	2A	2B	3A	3B	4A	4B	5A	5B
Copepoda									
Calanoida	0	0	0	0	0	2	0	0	0
Gastropoda	0	1	3	0	0	0	0	0	0
Pleuroceridae									
Elimia spp.	0	0	0	0	0	0	1	0	0
Hydracarina	14	58	28	2	0	14	1	0	1
Nematoda	18	22	8	11	2	7	1	0	2
Oligochaeta	48	48	36	34	16	78	8	20	9
Turbellaria									
Planariidae	0	7	1	0	0	1	3	1	0
Total number of taxa per station	23	39	31	32	18	37	19	25	22
Total number of organisms per station	197	417	183	173	84	391	41	119	81
Mean number of organisms per m²	14101	29848	13099	12383	6012	27987	2935	8518	5798