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Benthic meiofauna responses to five forest harvest methods

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Abstract

Benthic meiofauna were collected from the pools of minute (0 order) streams in the Ouachita National Forest, Arkansas during March 21–23, 1996 to see if benthic communities responded to forest harvest methods in a similar manner as plankton communities collected two years prior. The study streams and their watersheds (2–6 ha) were located in 14–16 ha forest stands that were selected for comparability of stands. Five treatment stands were paired with adjacent undisturbed reference stands (10 total). Treatment stands were subjected to one of five harvest methods listed in order of decreasing severity of harvest disturbance to the stands: (1) clearcut; (2) pine seed-tree; (3) pine shelterwood; (4) pine-hardwood group selection; and (5) pine single-tree selection. The mean number of taxa per site was 14 with a range of 9–20 taxa including rotifers, copepods, nematodes, dipterans, ostracods and 'other' meiofauna. Densities of total meiofauna (mean=2449 No. l^{-1}) were significantly higher (p= 0.002) in treated sites. Highest densities occurred in single-tree and clearcut treatments. Rotifers were significantly more numerous at the single-tree treatments (p=0.03) and nematodes were significantly greater at the clearcut treatments (p=0.03). We conclude that benthic meiofauna in these headwater streams are sensitive to silviculture practices and that the impact of forest harvest persists for at least 2.5 years.

Introduction

Although considerable interest in stream meiofauna has developed recently (Richardson, 1991; Ward & Palmer, 1994; Palmer et al., 1995; Robertson et al., 1995), there remains a paucity of data describing taxonomic assemblages in headwater streams and their responsiveness to environmental disturbances. Meiofauna may be an important ecological (trophic) component of these stream communities (Strayer & Likens, 1986; Brown et al., 1989, Borchardt & Bott, 1995; Pope, 1999). Meiofauna may also be valuable indicators of the environmental quality of watershed ecosystems. Fish, macroinvertebrates and algae species assemblages have been used extensively for bioassessment (Barbour et al., 1999), but not meiofauna. An important assumption for taxa used for bioassessment is that they are randomly distributed among similar habitats prior to treatment or perturbation (Karr, 1981; Karr et al., 1986). The utilization of fish and macroinvertebrate assemblages as bioindicators of disturbance is limited by knowledge of expected species composition of communities by ecoregion (Hughes et al., 1986; Hughes, 1995; Omernic, 1995; Barbour et al., 1999). Despite their limited mobility, meiofauna are highly vagile resulting in an almost cosmopolitan distribution of many taxa (Pennak, 1989). Thus, they should be a good candidate for bioassessment.

This study compared the benthic meiofauna taxa and densities among ten very small (2–6 ha) watersheds, five of which were subjected to different forest harvest techniques and paired with five reference watersheds. This was one of a series of studies to experimentally assess the ecological impacts of various forms of silviculture in the Ouachita National Forest, Arkansas. In a previous study, we examined these same small (0 order), headwater streams with intermittent flow to see if meiofauna were present as plankton in water above the substrate and if the assemblages varied with silvicultural practices (Smith et al., 2001). We observed a reasonably diverse community (*n*=42 taxa) but with very low densities of meiofauna in the plankton (1 No. l^{-1}). The plankton assemblage varied with silvicultural practices with the greatest densities occurring in pools located in watersheds subjected to silvicultural treatments. Brown et al. (1997) performed a similar analysis of benthic macroinvertebrates in these spring pool sites in 1994 and found significant differences in taxa composition and abundance between reference and treatment sites and among treatments. But, the taxa composition varied enough among sites without regard to treatment to preclude some bioassessment possibilities.

For this study, we collected benthic samples in 1996 from the same sites to determine if the benthic meiofauna were randomly distributed and if benthic communities responded to treatments similarly to the planktonic meiofauna. If differences were observed among sites, did differences persist between harvested and reference watersheds for the 2.5-year period?

Methods

The watersheds studied were located in 14–16 ha forest stands that were chosen based on the characteristics of the stands (for use in other studies) and not the watersheds. Stands were composed of mature shortleaf pine (*Pinus echinata*) with mixed hardwoods located on south, southeast, or southwest facing slopes of 5–20% (Mersmann et al., 1994). The characteristics used to compare stands included tree species composition, age, soil characteristics, slope and aspect. Each of five treatment stands was paired with an adjacent undisturbed reference stand. Each of the 10 stands contained two to four complete watersheds, however, only one or two watersheds in each stand had permanent spring pools along an intermittent stream channel.

Treatment stands were subjected to one of five harvest methods, listed in order of decreasing severity of harvest disturbance to the forest stands: (1) clearcut; (2) pine seed-tree; (3) pine shelterwood; (4) pine-hardwood group selection; and (5) pine single-tree selection (Smith, 1962; Baker, 1994a,b). The first three are even-aged and the remaining are uneven-aged silvicultural methods. All treatment stands had a 10 m buffer of undisturbed forest left on each side of the small streams. Refer to Baker (1994a, b) and Smith et al. (2001) for a further description of the study sites and silvicultural methods.

The streams studied were typical of the region, being very small (0 order, *sensu* Strahler, 1957) with 2–6 ha watersheds. Most existed as isolated spring pools, each ranging from 0.1 to 1 m^2 with a maximum depth ranging from 15 to 35 cm, except during rainstorms. Because these pools are separated by dry land 355–360 d yr^{-1}, we consider the study to be replicated at the pool habitat level but not completely replicated at the stand level or the watershed level. Smith & Pearson (1987) determined that small pools in intermittent streams quickly develop individual characteristics despite close proximity. We assume the same holds true for these small pools.

Silvicultural treatments were performed from June-September 1993. Benthic meiofauna samples were collected March 21–23, 1996. Samples were collected by removing 0.3 l of sediment within a 76.5 cm^2 area to a maximum depth of 10 cm. Each sample was swirled and decanted to remove meiofauna from large inorganic substrate and then concentrated using a Wisconsin bucket. Any leaves or debris collected were rinsed thoroughly and the wash was included in the sample. Three samples were collected from separate pools located in each of the five treatment areas and three from their reference areas (*n*=30).

Meiofauna samples were preserved in 5% formalin with Rose Bengal stain upon collection. Subsamples were examined until a minimum of 200 individuals were counted. Rotifers, cladocerans and copepods were identified to the lowest taxa feasible (often genus) and recorded as present or absent at sites. Because not all individuals were identified to the genus level, we chose to use major taxonomic categories for statistical tests. Herman & Heip (1988) determined that using higher taxonomic categories is sufficient for distinguishing assemblages.

Statistical analyses

The selection of study sites was based on comparability of forest stands prior to treatment, not specific watersheds within the stands. We were unable to collect data before the forest harvest treatments, but we were able to collect data from reference sites adjacent to treatments. We assumed that all sites were equivalent prior to treatment if there were no significant differences among the references. To test this, we compared meiofauna data from reference sites using Proc GLM (SAS, 1999–2000). We found that reference sites were statistically equivalent for total meiofauna, rotifers, cyclopoid copepods, harpacticoid copepods, nauplii, dipterans, nematodes and 'other' meiofauna (p=0.94, 0.20, 0.60, 0.41, 0.66, 0.27, 0.88 and 0.60, respectively). In a previous study examining plankton, the densities of meiofauna collected from these reference sites were statistically equivalent for total meiofauna, cyclopoid copepods, nematodes, ostracods and 'other' meiofauna (Smith et al., 2001).

For those taxa that did not vary significantly among reference sites, we concluded that any statistical differences would be due to treatments (forest harvest method). If the taxa did not vary significantly among reference sites, we used a Proc GLM (SAS, 1999–2000) to test the comparability of forest harvest treatments. It should be noted that the GLM analysis was performed on log-transformed data to meet the assumption of equal variances for all taxa except nauplii, which met the assumption without transformation.

Proc GLM (SAS, 1999–2000) was used to determine if there were differences among the five sites (a site was composed of each treatment stand and its adjacent reference) and forest harvest (at two levels: treatment and reference) and also to determine if there were interactions between these two variables. Where there was no significant interaction, this analysis was used to address the objective assessing whether treatment stands differed from reference stands.

The abundance of each meiofauna taxon (e.g. genus) was not determined in this study. Therefore, the Jaccard index of similarity, which compares only presence/absence of taxa, was used to examine differences in assemblages among sites.

Results

The benthic meiofauna in these minute streams were relatively abundant with a mean density of 2449 No. l^{-1}. We collected 41 different taxa, including 16 rotifer genera (Table 1). The number of taxa observed per site ranged from 9 to 20 with a mean of 14. The benthic community was dominated by rotifers, which comprised 40.8% of total meiofauna density. The remaining groups consisted of: copepod nauplii 16.2%, nematodes 16.0%, harpacticoids 14.5%, 'other' meiofauna 6.4%, cyclopoids 2.8%, dipterans 1.8% and ostracods 2.5%. No significant differences in the mean number of taxa were observed among treatments (p=0.68), although higher total numbers of taxa occurred at the single-tree treatment sites (Fig. 1). Jaccard index of similarity values among reference sites (0.39), among treatments (0.48), and between references and treatments (0.57) indicate moderate similarities of community composition.

Mean densities of total meiofauna varied significantly between reference sites and treatments (p=0.002) with greater numbers occurring at treated (forest harvest) sites (Fig. 2). The highest densities

Table 1. Occurrence of rotifer, cladocera, cyclopoid and harpacticoid copepod genera. Presence is indicated by X. The five treatments are presented in Figure 1

	Treatment					Reference				
	CC	SE	SW	GS	ST	CC	SE	SW	GS	ST
Rotifers										
Ascomorpha		X				X	X			
Brachionus				X						
Cephalodella			X			X				
Conochiloides					X					
Euchlanis					X	X			X	X
Gastropus			X					X		
Hexarthra										X
Keratella										X
Lecane	X	X			X		X			
Lepadella						X				X
Macrochaetus			X				X			
Monostyla					X	X				
Notommata	X				X				X	
Pleosoma					X					
Tricotria		X	X	X	X	X				X
Trichocerca	X				X	X	X	X		X
Cladocerans										
Alona						X				
Bosmina						X				
Chydorus						X				
Leydigia					X					
Cyclopoids										
Acanthoyclop	X	X	X	X	X	X	X	X		X
Cyclops	X									
Ectocyclops	X									
Eucyclops							X			
Orthocyclops					X					
Paracyclops		X	X							
Harpacticoids										
Attheyella	X	X	X	X	X	X	X	X	X	X
Bryocamptus										X
Canthocamptus		X					X			
Elaphoidella	X									
Maraenobiotus				X						X
Nitocra			X					X		
Nitocrella										X

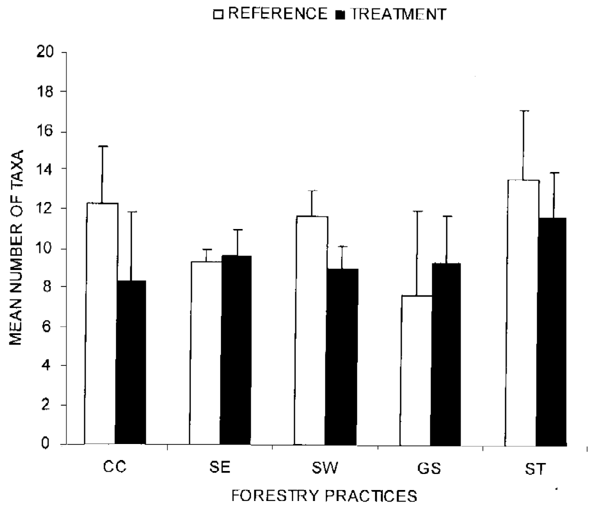

Figure 1. Mean number of benthic meiofauna taxa collected from treatment and reference stands in the Ouachita National Forest. The five treatments were: clearcut (CC), seed-tree (SE), shelterwood (SW), group selection (GS) and single-tree selection (ST). Error bars are +2 standard error of the means. Refer to Baker (1994a, b) and Smith et al. (2001) for a further description of silvicultural methods.

Table 2. Mean percent density (No. l^{-1}) of each meiofauna taxon in small pools in the Ouachita National Forest, Arkansas. The five treatments are listed in Figure 1

	Treatment					Reference				
	CC	SE	SW	GS	ST	CC	SE	SW	GS	ST
Rotifera	30.0	48.1	26.2	43.0	55.4	53.0	48.9	19.8	24.1	33.7
Ostracoda	8.8	3.0	1.4	0	0.9	1.7	0	0.2	0.1	2.3
Cyclopoida	0.8	3.8	1.2	1.7	0.8	6.9	4.0	2.1	2.2	15.9
Harpacticoida	6.1	6.5	31.4	21.2	15.6	10.0	5.9	34.3	16.8	9.6
Nauplii	12.4	12.4	20.8	8.4	11.2	21.5	14.2	29.6	31.6	16.6
Nematoda	40.1	23.0	12.1	15.4	4.7	8.3	20.3	7.5	20.3	21.1
Diptera	0.7	0	4.9	1.5	0.9	1.8	0	1.9	1.0	4.7
Others	3.5	5.4	5.4	10.5	5.1	9.6	7.6	6.4	9.2	9.4

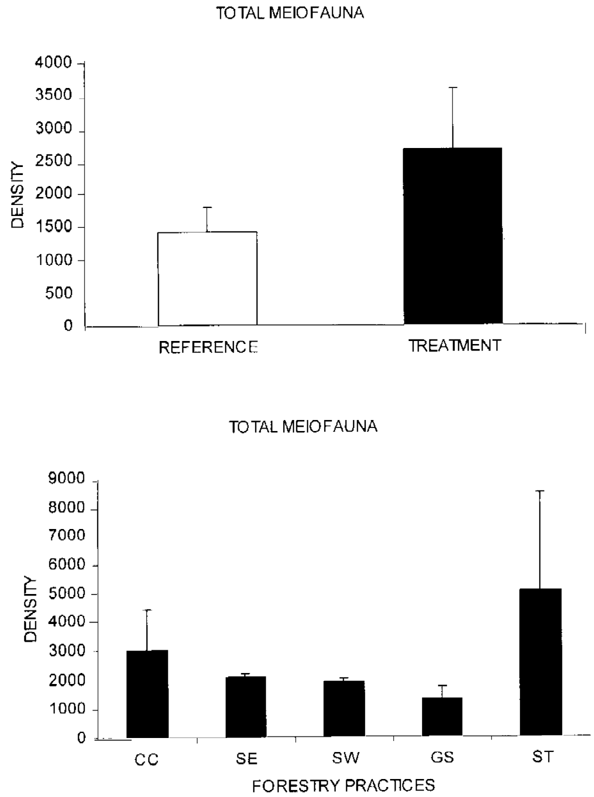

Figure 2. Mean densities (No. l^{-1}) of total meiofauna collected from small pool habitats in reference and treatment forest stands in the Ouachita National Forest, Arkansas. Mean densities of total meiofauna collected from treated (forest harvest) sites. Error bars are +2 standard error of the means. The five treatments are presented in Figure 1.

were found at the single-tree and clearcut treatments (Figure 2). Total meiofauna densities were dominated by rotifers and nematodes (Table 2). Mean densities of rotifers and nematodes were significantly higher in treated sites than in reference sites (p=0.01 and 0.03, respectively) (Fig. 3). Rotifers also varied among sites (p=0.04) with the greatest densities at single-tree sites (Fig. 4). Nematodes were numerous in clearcut treatment sites.

Harpacticoid copepods and dipterans both varied among sites (p=0.0009 and 0.002, respectively) (Fig. 5). Both taxa were found in the greatest densities at the shelterwood sites. In the case of dipterans, the high numbers at the shelterwood sites correspond to a significant difference among treatments (p=0.01) with high densities at the shelterwood treatments (Fig. 6). Cyclopoid copepods, copepod nauplii, ostracods and 'other' meiofauna comprised 27.9% of the total meiofauna collected from the benthos. None of these taxa varied significantly between references and treatments (p=0.99, 0.85 and 0.85 and 0.73, respectively), nor among treatments (p=0.60, 0.053, 0.08 and 0.18, respectively).

Discussion

The minute, headwater streams used in this study contained a diverse and abundant benthic meiofauna community with densities equivalent to those found in the substrate of the 4th order Illinois River, Arkansas (Smith, unpublished data). Benthic densities were

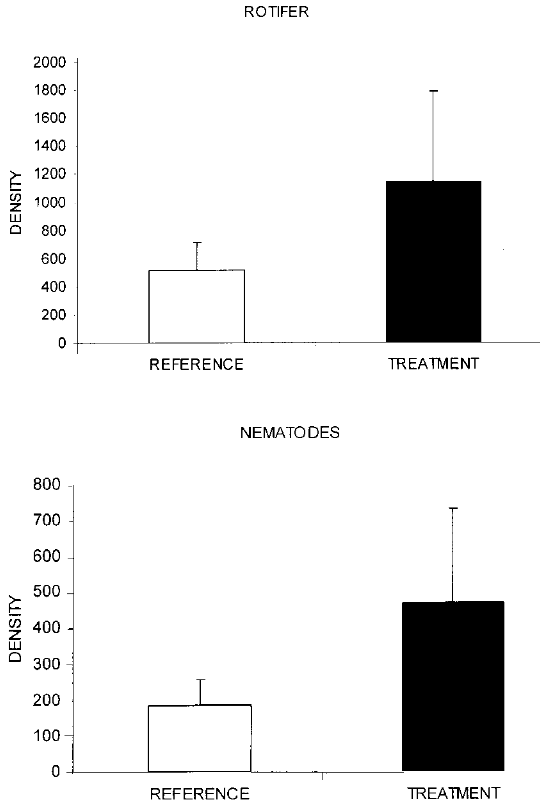

Figure 3. Mean densities (No. l^{-1}) of rotifers and nematodes collected from small pool habitats in reference and treatment forest stands. Error bars are +2 standard error of the means. The five treatments are presented in Figure 1.

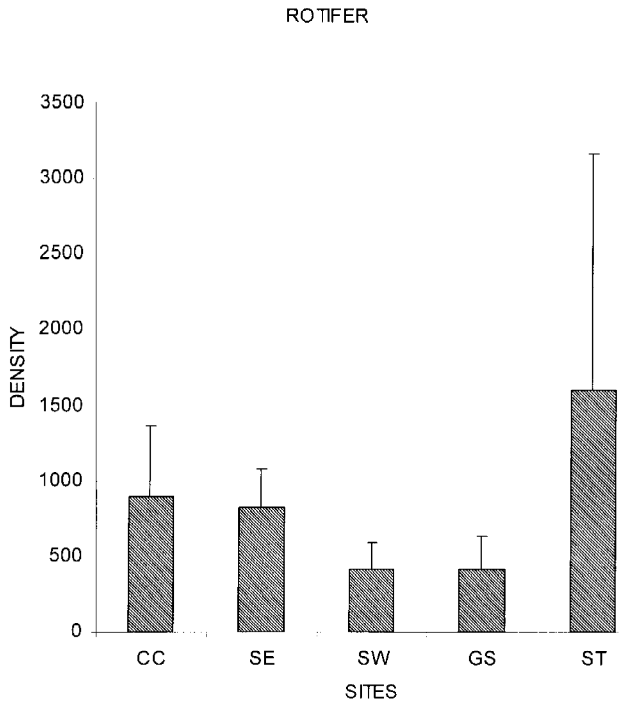

Figure 4. Mean densities (No. l^{-1}) of rotifers among sites. Error bars are +2 standard error of the means. The five treatments are presented in Figure 1.

about 2000 times greater in the study pools than reported in the plankton during a prior study at the same sites (Smith et al., 2001). Despite greater densities, the number of taxa collected from the benthos showed similar trends to the prior plankton study with 41 taxa collected in the benthos and 42 taxa collected in the plankton (Fig. 7). Benthic taxa in this study were more evenly distributed among sites than were plankton in the 1994 study, as indicated by higher Jaccard index of similarity values and greater mean number of taxa at sites.

There appears to have been a shift in the dominant taxa from copepods (53%), which dominated the plankton in 1994, to rotifers (40.8%) in the benthos in 1996. This could be due to differences in habitats sampled (planktonic vs. benthic). Despite the apparent shift in dominant taxa, nematodes (16%) comprised about the same percentage of the community in both studies. Although copepods were abundant in both studies, they did not show a significant preference for sites, except for harpacticoids in the benthos.

Benthic meiofauna at the study sites appeared to vary with silvicultural treatments. Densities of total meiofauna were higher in treatment sites than in adjacent reference sites. The highest densities of meiofauna occurred in the least severe uneven-age treatment (single-tree) and the most severe even-age treatment (clearcut). Rotifers and nematodes were primarily responsible for the high densities in these treatments. Rotifer densities were significantly higher at the single-tree treatment and nematode densities were significantly higher at the clearcut treatment. No reason for the observed differences in taxa composition among treatments was evident at the time of sampling.

High densities of macroinvertebrates (Brown et al., 1997) and planktonic meiofauna (Smith et al., 2001) have been recorded for the same single-tree treatment sites in 1994 just as for benthic meiofauna in the current study. All three taxonomic groups (macroinvertebrates, planktonic meiofauna and benthic meiofauna) responded to forest harvest with increased densities at treatment sites. All three groups

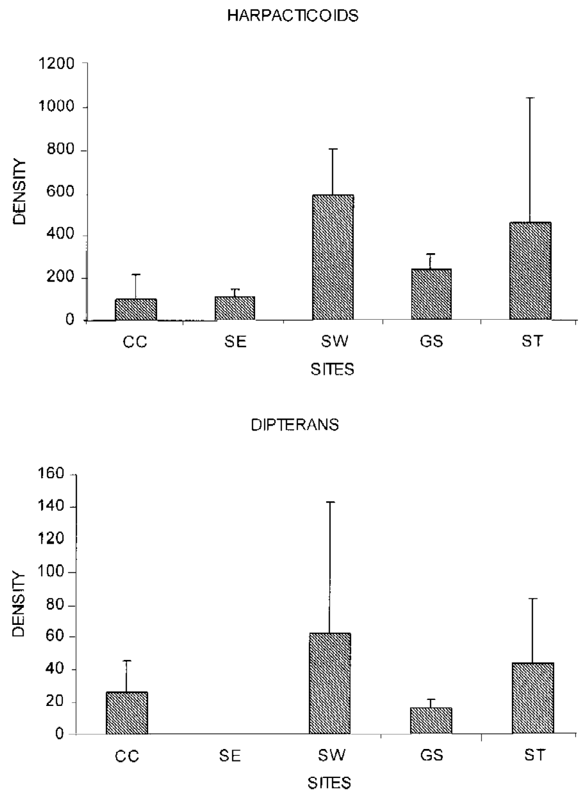

Figure 5. Mean densities (No. l^{-1}) of harpacticoids and dipterans among sites. Error bars are +2 standard error of the means. The five treatments are presented in Figure 1.

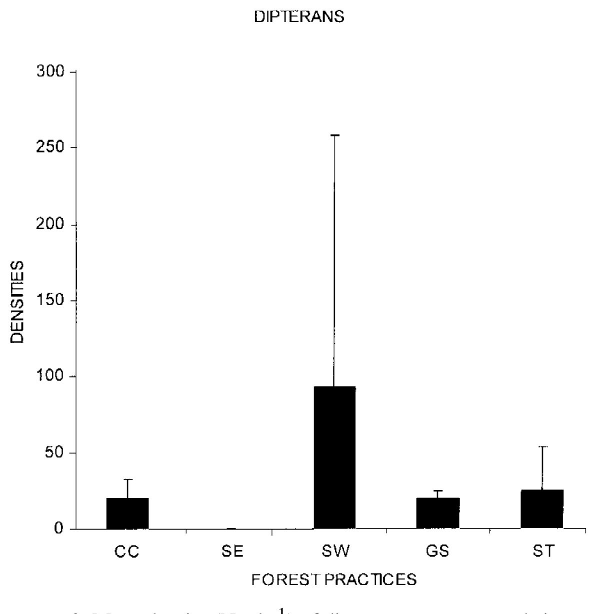

Figure 6. Mean density (No. l^{-1}) of dipterans among treated sites. Dipterans were not collected from seed-tree treatment sites. Error bars are +2 standard error of the means. The five treatments are presented in Figure 1.

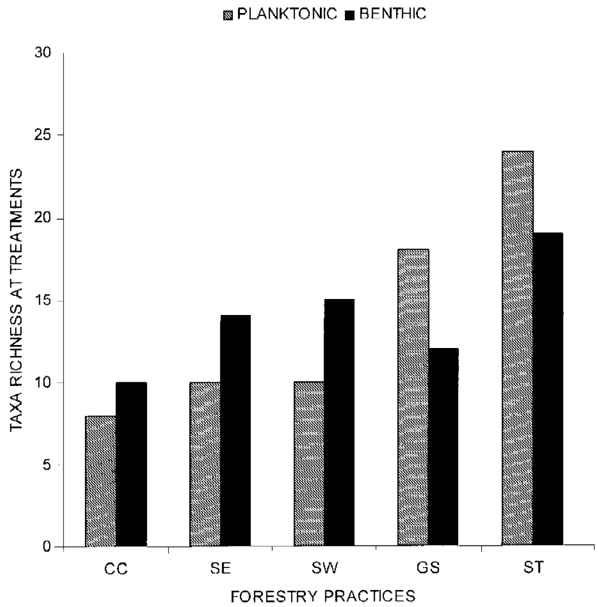

Figure 7. Taxa richness of benthic meiofauna from this study and planktonic meiofauna from two years prior (Smith et al., 2001). Taxa richness represents the pooled number of unique taxa collected from treatment sites. The five treatments were: clearcut (CC), seed-tree (SE), shelterwood (SW), group selection (GS) and single-tree selection (ST).

were also found in the greatest abundance at the single-tree and/or clearcut treatment sites. Because the single-tree treatments remain significantly different from other sites, we conclude that these habitats were still recovering from forest harvest ca. 2.5 years after forest harvest.

The use of benthic meiofauna in monitoring may provide some advantages over meiofauna collected from the plankton. Benthic meiofauna can be collected easily and do not require special equipment. However, more time is required for examination of benthic samples because the researcher must sort through detritus collected with benthic meiofauna samples. Rose Bengal stains the meiofauna bright pink aiding this process. The comparative number of taxa collected in planktonic and benthic samples (Fig. 7) suggests that planktonic samples may sufficiently represent meiofaunal taxa diversity, but densities of benthic meiofauna (2449 No. l^{-1}) far exceeded those of planktonic meiofauna (1 No. l^{-1}). Density could be an important consideration when sampling from very small pools like these.

The results of this study and comparisons with two previous studies in the same pool habitats (Brown et al., 1997; Smith et al., 2001), indicate that meiofauna may be used as a good bioassessment tool for environmental disturbances. The relatively low levels of disturbance caused by these forest harvest methods corresponded with significant differences between meiofauna in treated and reference watersheds, and among forest harvest treatment types despite the presence of a 10 m buffer strip. These patterns were similar among total benthic meiofauna, total planktonic meiofauna and total macroinvertebrates, but varied considerably among more specific taxa in each group.

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