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Benthic Macroinvertebrate Responses to Reduced Summer Streamflows in a Northern Michigan Stream

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Abstract.–We evaluated the response of benthic macroinvertebrates in a Michigan trout stream to flow reduction by diverting water from a 602-m reach of Hunt Creek from June through August of 1994, 1997, and 1998. We also assessed the utility of the Physical Habitat Simulation system (PHABSIM) in predicting the response of benthic insects to water withdrawals by testing the assumption of a positive linear relationship between modeled habitat (weighted usable area, WUA) and the density of 13 benthic insect families. Our findings showed that the density of filter feeding and grazing insect taxa, as well as insects classified as obligate erosional zone taxa, declined significantly in the dewatered (treatment) zone (TZ) when 90% of flow was diverted. Density of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa in the TZ was significantly lower when 90% of water was diverted as compared to density at baseflow or when flow was reduced by 50%. The density of all insects in an upstream reference zone riffle (RZ), where flow was not altered, did not change between experimental periods. Although overall reductions in the density of benthic insects at 90% flow reduction coincided with lower PHABSIM predictions of WUA, we found poor linear correlation between WUA at different flows and the density of the 13 benthic insect families for which WUA was modeled. The low proportion of variation explained by WUA for all families modeled suggests that WUA alone is not an accurate predictor of benthic insect density. Resource managers should consider the potential consequences of water withdrawals to all components of stream communities, including benthic macroinvertebrates. However, caution should be applied when using the labor-intensive PHABSIM system in high-quality trout streams such as Hunt Creek, because most relationships between WUA and benthic insect density were insignificant.

Introduction

Increasing water withdrawals for agricultural, industrial, and domestic purposes in Michigan may adversely affect stream communities. The area of land irrigated for agricultural purposes in Michigan increased from 39,255 ha to 159,042 ha statewide between 1974 and 1997 (USDA

1999). Seasonal withdrawals to irrigate golf courses accounted for an additional 15,378 ha of land in Michigan in 1999 (Michigan Water Use Reporting Program, unpublished data). Such increases in water use are a potential threat to stream ecosystems and raise concerns about the effects of water withdrawals on all components of Michigan's stream communities, including benthic macroinvertebrates.

Benthic macroinvertebrates are an important food source for fishes, including ecologically and economically significant salmonid species (Elliott 1973; Alexander and Gowing 1976; Allan 1981; Bechara et al. 1982; Nielsen 1992). Macroinvertebrates are also crucial to nutrient cycling and energy flow through lotic systems (Rader and Belish 1999). For example, Chapman (1966) noted that the density of macroinvertebrates and their occurrence in the drift have the potential to limit the growth rate of individual fish and the size of the population. Rader and Belish (1999) noted that there is a wealth of literature suggesting macroinvertebrate communities are tightly linked to instream hydraulic conditions such as flow variation. Although numerous studies have examined the effects of increased flow conditions on macroinvertebrates (Boulton et al. 1992; Cobb et al. 1992; Imbert and Perry 2000), few reports exist on the effects of dewatering (reducing flow) on invertebrates. Studies that have examined the effects of dewatering on macroinvertebrates have primarily been undertaken in other countries (O'Keefe and DeMoor 1988; Dudgeon 1992; Castella et al. 1995), or in streams in the western United States not comparable to those found in Michigan (e.g., McClay 1968; Rader and Belish 1999).

Concerns about the effects of excessive water withdrawals on stream communities in the western United States led to the development of the Instream Flow Incremental Methodology (IFIM), a protocol for protecting stream flows that is dependent upon field data collection, habitat modeling, and negotiation over the projected effects of reduced streamflow on fish and aquatic habitat (Milhous et al. 1989). Although the IFIM, including its suite of habitat modeling programs collectively known as the Physical Habitat Simulation system (PHABSIM), has been widely applied in the western United States, the system has not been extensively used in Michigan to evaluate the effects of water withdrawals (Gowan 1984; Reiser et al. 1989; Bovee et al. 1994; Baker and Coon 1995a, 1995b; Nuhfer and Baker 2004).

Baker and Coon (1995b) developed habitat suitability criteria (HSC) from benthic macroinvertebrate samples collected from Hunt Creek, Michigan and used PHABSIM to predict habitat availability for major taxa at different levels of stream discharge. They predicted that a water withdrawal of 50% would reduce habitat of riffle dwelling taxa, such as Heptageniidae, but would have little effect on most other taxa examined. Heptageniidae density in a treatment riffle (50% flow reduction) did decrease significantly in relation to a control riffle, and total density of benthic macroinvertebrates did not change. Several other studies have documented habitat use patterns of benthic macroinvertebrates and have published HSC which could be used in a PHABSIM analysis (Gore and Judy 1981; Orth and Maughan 1983; Gore 1989), but the availability of these data has not lead to an increase in the use of benthic macroinvertebrates in predicting the effects of flow alteration in streams (Baker and Coon 1995b). Bovee (1985) studied the effects of a peaking hydropower operation on benthic macroinvertebrate habitat in a Colorado stream but did not compare the weighted useable area (WUA) projections from the PHABSIM modeling to observed benthic macroinvertebrate abundance. Likewise, Gowan (1984) modeled the habitat of two genera of macroinvertebrates in a marginal Michigan trout stream, but did not compare the PHABSIM model output with observed macroinvertebrate densities.

The objectives of this study were to 1) evaluate the response of the benthic macroinvertebrate community in Hunt Creek to simulated irrigation withdrawals by determining the effects of dewatering on benthic macroinvertebrate density, and 2) determine if densities of select benthic insect families were correlated with PHABSIM projections of WUA at different discharge levels.

Methods

Study Stream

Hunt Creek is a groundwater-dominated tributary to the Thunder Bay River in Michigan's northern Lower Peninsula (Figure 1). The Hunt Creek watershed lies in northern Oscoda and southern Montmorency counties and drains extensive glacial sands and gravels deposited approximately 10,000 years ago (Dorr and Eschman 1970). Due to the geology of the watershed, Hunt Creek has extremely stable discharge: at the downstream end of the study area, the 90% exceedence flow was 0.75 m^3/s and the 10% exceedence flow was 0.87 m^3/s from 15 March 1999 to 15 March 2001 (Nuhfer and Baker 2004). Hunt Creek is a second-order stream upstream of the confluence with Fuller Creek, which flows into Hunt Creek immediately above the treatment zone (Figure 1), and is a third-order stream through the remainder of the study area. Common fish species in Hunt Creek include brook trout *Salvelinus fontinalis*, mottled sculpin *Cottus bairdi*, and slimy sculpin *Cottus cognatus* (Alexander and Hansen 1986).

Water Diversions

To determine species-specific habitat-discharge suitability relationships and test PHABSIM, Nuhfer and Baker (2004) divided a study area of Hunt Creek into three contiguous sections: a 1,254-m upstream reference zone (RZ), a 602-m treatment zone (TZ), and a 1,534-m downstream RZ (Figure 1). In 1989–90, a diversion channel was excavated around the TZ. Bulkheads were installed at the upstream and downstream ends of the TZ as a means of controlling discharge and to support traps used in monitoring fish movement. The upstream bulkhead diverted water around the TZ (simulating irrigation withdrawals) from 1 June to 31 August of each year in 1991–98. During 1991–94, 50% of the streamflow was diverted from the TZ, followed by a 75% diversion of streamflow in 1995–96 and a 90% diversion of streamflow in 1997–98.

Construction of HSC

Macroinvertebrate abundance and habitat data were collected in the TZ of Hunt Creek in 1992–93 to construct HSC for use in the PHABSIM analysis. Methods for estimating macroinvertebrate abundance and construction of HSC were described in Baker and Coon (1995b). Prior to sampling macroinvertebrates and macroinvertebrate habitat, they divided the TZ into seven contiguous reaches, each approximately 50 m in length, and omitted the small area of impounded water at the downstream end of the TZ and the disturbed habitat at the upstream end of the TZ immediately below the bulkhead.

Baker and Coon (1995b) collected benthic macroinvertebrates and depth, velocity, and substrate data from randomly selected locations in the TZ during May–September, 1992, and April–September, 1993 to construct HSC. They constructed HSC for macroinvertebrate families from combined data collected in 1992–93 in the TZ using the nonparametric tolerance limits method described in Bovee (1986). Due to concerns regarding statistical independence of the observations, they did not weight the value of the habitat measured at a sample location by the number of organisms in the sample, which resulted in HSC constructed from presence-absence data only. They also did not correct the HSC based on habitat availability because sample sites were randomly selected and therefore sampled in approximate proportion to their availability.

PHABSIM Modeling

Baker and Coon (1995b) used a representative reach approach for modeling the habitat in the TZ by selecting two of the 50-m reaches in the TZ (reaches B2 and B4, Figure 1) for PHABSIM analysis. They established transect locations in each of the reaches and used changes in mesohabitat (riffle, run, pool) within each reach to guide transect placement. Depth, velocity, and substrate data were collected along each transect at three discharges: 0.46 m^3/s (0% flow reduction), 0.23 m^3/s (50% flow reduction), and 0.11 m^3/s (75% flow reduction). Baker and Coon (1995b) used

PHABSIM to make projections of WUA for selected benthic insect families over a range of flows from summer baseflow down to 2% of summer baseflow (0.01 m^3/s) for the reaches in the TZ. They selected families for PHABSIM modeling based on their frequency of occurrence in the 1992–93 samples and their habitat use characteristics (e.g., erosional vs. depositional areas). Habitat (WUA) was modeled for insect families that occurred in 20–80% of the samples in 1992–93, as well as additional families (Table 1) to provide data for habitat types that were not adequately represented in the initial selection procedure.

Macroinvertebrate Abundance

Macroinvertebrate abundance data were collected at 50% flow reduction in 1994 (Baker and Coon 1995b) and at 90% flow reduction in 1997 and 1998. Macroinvertebrate collection and enumeration procedures for 1997–98 followed the protocols for 1994 detailed in Baker and Coon (1995b). Because early results of the PHABSIM modeling by Baker and Coon (1995b) indicated that riffle-dwelling insects were more likely to be affected by flow reductions than insects more commonly found in pool or depositional habitats, two riffles were selected (one each in the TZ and upstream RZ; hereafter referred to as the RZ) that had similar microhabitat characteristics under baseflow conditions in 1994. The microhabitat characteristics (depth, mean column velocity, and substrate) of the riffle selected in the TZ were very similar to those found in the riffle habitat in reach B2. They measured the width and length of each of the selected riffles and, using permanent markers in the stream bank, established a two-dimensional grid of cells, each cell being approximately the same size as the area sampled by a Hess sampler (0.023 m^2). Benthic macroinvertebrate samples were collected in seven randomly selected cells in each riffle at approximately three week intervals from April or May to August during 1994, 1997, and 1998. Additional samples were collected from each riffle in October of 1997 and 1998.

We moved upstream through each riffle and collected samples from each of the randomly selected cells with a modified Hess sampler constructed of 500-µm mesh. Upon collection, benthic samples were preserved in 95% ethyl alcohol and returned to the laboratory for processing. Macroinvertebrates were separated from inorganic material in the samples by floating sample contents in a saturated sugar solution (Anderson 1959). All macroinvertebrates were identified to family using the keys in Hilsenhoff (1995), Merritt and Cummins (1984), and Pennak (1989). Laboratory personnel counted the number of organisms in the sample by family and converted to density estimates by dividing by the sampled area (0.023 m^2). Sample data were not adjusted for the efficiency of the sugar floating procedure because the process is very efficient (Baker and Coon 1995b).

Statistical Analysis

We used mixed-effect analysis of variance (ANOVA) to evaluate the response of the benthic macroinvertebrate community in Hunt Creek to simulated irrigation withdrawals by comparing macroinvertebrate density in the TZ and RZ across three levels of flow reduction. We treated taxon group, functional feeding group or habitat guild, stream section (TZ or RZ), and level of flow reduction (0%, 50%, or 90%) as fixed effects and sampling date as a random effect. We assigned organisms to functional feeding group (filter feeder, grazer, predator, or shredder) or habitat guild (obligate erosional, obligate depositional, and erosional and depositional) using the ecological tables presented in Merritt and Cummins (1996). In cases where the level of taxonomic identification required to functionally classify benthic insect families was not achieved (i.e., Tipulidae and Ephemerellidae), we assigned a functional feeding group or habitat guild to that family using the classification of the genus that most commonly occurred in Hunt Creek during the years of study (T. C. Wills, MDNR, unpublished data). Data collected prior to 1 June of each year of sampling were used to represent baseflow (0% flow reduction) conditions. We excluded data collected in October of 1997 and 1998 from all analyses, because flow reductions in the TZ were discontinued after 31 August of each year of sampling and flows at this time

were often above baseflow. We used a one-way ANOVA and Tukey's Honestly Significant Difference (HSD) test to identify significant differences in macroinvertebrate density at different levels of dewatering in the TZ. The same method was used to compare density between experimental periods in the RZ where flow was not altered. The data were transformed to meet the distributional assumptions of the model when appropriate, and rejection criterion was set at $\alpha = 0.05$ for all analyses.

Densities of insect families selected for habitat modeling were regressed against WUA to determine if a significant linear relationship existed between insect density and WUA. Because the riffle sampled in the TZ was close to reach B2 and similar to the riffles in reach B2, we regressed predictions of WUA in reach B2 against insect densities collected from the riffle sampled in the TZ at 0%, 50%, and 90% flow reductions. We used WUA projections from the PHABSIM model developed by Baker and Coon (1995b) at 91% reduction in baseflow (Table 2) as a surrogate for WUA at 90% reduction in baseflow. Rejection criterion was again set at $\alpha = 0.05$ for all analyses. All data analysis was done with SPSS version 11.5 (SPSS 2002).

Results

PHABSIM Model Predictions of WUA

The results of HSC construction and PHABSIM modeling were summarized in Baker and Coon (1995b). The 50% reduction in summer stream flow in the TZ resulted in a minor loss of stream surface area (5.3%) in the modeled reach (B2), as total surface area decreased from 206 to 195 m^2/100 m. Surface area was predicted to decline 29% in reach B2 when flow was reduced 90% (Figure 2).

Estimated WUA for a 50% reduction in flow was higher than at baseflow in reach B2 for all but three of the 13 taxa modeled (Elmidae adults, Heptageniidae, and Rhyacophilidae, Table 2). The increases in WUA ranged from 0.7% for Perlodidae to 22.1% for Tipulidae. In general, taxa that were most commonly found in pool and depositional habitats had the largest increases in WUA, while Elmidae adults, Heptageniidae, and Rhyacophilidae had minor losses in WUA (4.1–14.8%). Reducing flow to 90% of summer baseflow resulted in a loss of WUA for all taxa modeled. WUA loss ranged from 26.3% to 88.7% (Ceratopogonidae and Elmidae adults, respectively). WUA estimates for more than half of the taxa modeled declined more than 70% (compared to baseflow) at a 90% reduction in summer stream flow (Table 2).

Effects of Water Withdrawal on Benthic Macroinvertebrate Abundance

Total macroinvertebrate density.–Benthic macroinvertebrates representing 7 classes, 16 orders, and over 40 families were present in a total of 221 samples collected during 1994, 1997, and 1998 (Table 1, Appendix A–C). Macroinvertebrates from the class Insecta were most common and occurred in 100% of the samples, followed by classes Malacostraca (94.6%), Oligochaeta (54.8%), Arachnida (33.9%), Bivalvia (4.1%), Gastropoda (2.7%), Turbellaria (1.8%), and Hirudinea (0.5%).

The total density of benthic macroinvertebrates from all classes combined varied by stream section and level of flow reduction as indicated by the presence of a significant stream section*flow reduction interaction (Table 3). Point estimates of mean total density in the TZ were nearly 19% higher than the RZ at baseflow and over 40% higher than the RZ at 50% flow reduction ($t = 2.21$, df = 13, $P = 0.046$). At 90% flow reduction, point estimates of mean total density were 41% lower in the TZ compared to the RZ ($t = 2.24$, df = 13, $P = 0.043$; Figure 3). Total invertebrate density significantly increased in the TZ when 50% of baseflow was diverted, but declined significantly when water diversions increased from 50% to 90% (Table 4).

Total insect density.–Total insect density of all orders combined varied significantly by stream section and level of flow reduction as indicated by the presence of a significant stream section*flow reduction interaction (Table 3). Mean total insect density in the TZ was significantly higher than in the RZ at 50% flow reduction ($t = 3.04$, df = 13, $P = 0.010$; Figure 3). However, the point estimate of mean total insect density in the TZ was nearly 107%

lower than the point estimate of insect density in the RZ at 90% flow reduction (t = 2.57, df = 13, P = 0.023). Total insect density in the TZ declined significantly when flow was reduced by 90% whereas no change in density was observed in the RZ (Table 4, Figure 3).

Density of insects by order.–The density of insects varied significantly by order and stream section (Table 3). However, the presence of a significant order*stream section*flow reduction interaction complicates interpretation of the data, as insect density varied by order across both stream sections and all three levels of flow reduction studied (Figure 4). Relatively abundant insects from the orders Coleoptera and Trichoptera followed a pattern similar to mean total insect density with greatest point estimates of mean density in the TZ occurring at 50% levels of flow reduction and very similar point estimates of mean density in the RZ across all levels of flow. Significant declines in the density of Coleoptera, Ephemeroptera, and Trichoptera occurred when the percentage of water diverted from the TZ was increased from 50% to 90% (Table 4). Conversely, density of these taxa did not change in the RZ. No significant differences between the density of Plecoptera, Diptera, or Megaloptera were detected in either zone. Benthic insects from the orders Heteroptera and Odonata were uncommon in both stream sections across all levels of flow reduction (Appendix A-C).

The pattern of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa density also mirrored that of total insect density, as sensitive EPT taxa comprised a large proportion of the benthic insects sampled in both the TZ and the RZ (Table 1, Appendix A–C). At baseflow, the point estimate of mean EPT density was significantly higher in the TZ compared to the RZ (t = 2.94, df = 13, P = 0.011). The mean density of EPT taxa in the TZ was higher compared to the mean density of EPT taxa in the RZ at 50% flow reduction (t = 2.84, df = 13, P = 0.014, Figure 3). At 90% flow reduction EPT taxa density in the TZ was lower than the point estimate of density in the RZ (t = 2.87, df = 13, P = 0.013). Density of EPT taxa in the TZ was significantly lower when 90% of water was diverted as compared to density at baseflow or when flow was reduced by 50% (Table 4, Figure 3).

Density of insects by functional groups.–The density of insects varied significantly by functional feeding group regardless of stream section or level of flow reduction, and by level of flow reduction regardless of functional feeding group or stream section (Table 5). However, the presence of significant stream section*flow reduction and functional group*stream section*level of flow reduction interactions indicated variability in the density of all insects between stream sections and among all levels of flow reduction. Density of grazers and filter-feeding taxa in the TZ declined significantly when 90% of water was diverted whereas no differences in density were evident in the RZ (Table 6, Figure 5). No differences in the density of predators or shredders between treatment levels were detected in either zone.

Density of insects by habitat guilds.–The density of insects varied significantly by habitat guild and stream section, but the response differed across levels of flow reduction as indicated by the presence of significant habitat guild*stream section, habitat guild*flow reduction, and stream section*flow reduction interactions (Table 5). Average density of obligate erosional taxa in the TZ declined dramatically from 1,452/m^2 at 50% dewatering to 180/m^2 when 90% of water was diverted, whereas no change occurred in the RZ (Table 6, Figure 6). No change in the density of obligate depositional taxa was detected in either zone. The pattern of density for obligate depositional taxa in the TZ paralleled that of the RZ, with higher estimates of abundance in the TZ across all levels of flow. Taxa that may occupy both erosional and depositional habitats were the most abundant insects encountered. Their density significantly increased in the TZ when 50% of baseflow was diverted, but declined significantly when water diversions increased from 50% to 90%. In the RZ, their density was similar between all periods (Table 6, Figure 6). Point estimates for taxa that use both habitat types were nearly identical at baseflow in the TZ and RZ. At 50% flow reduction, the point estimate of density was higher in the TZ compared to the RZ, and at 90% flow reduction,

the point estimate of density was lower in the TZ compared to the RZ.

Relationship of Benthic Insect Abundance to WUA

The density of 3 of the 13 insect orders selected for PHABSIM modeling was significantly correlated to WUA estimates derived from presence-absence HSC (Table 7). The most significant relationship between density and WUA was for Heptageniidae (Figure 7). Although Heptageniidae density was positively related to WUA and the proportion of variation explained by WUA was moderate (R^2 = 0.51), there was considerable scatter around the linear regression line. The only other insect taxa for which density was significantly and positively related to WUA were Empididae and Baetidae. Evidence of a positive relationship between density and WUA was present for Glossosomatidae (Figure 7), as well as Ephemerellidae, Elmidae adults, Hydropsychidae, and Nemouridae. However, scatter around the linear regression lines was considerable and the regression coefficients only approached significance, as the proportion of variation explained by WUA was small (R^2 = 0.19–0.26, Table 7). The relationships between density and WUA for Ceratopogonidae, Perlodidae, Rhyacophilidae, Simulidae, and Tipulidae were insignificant.

Discussion

Our results complement the results of previous studies. Total macroinvertebrate density and the total density of insect taxa (the most common benthic macroinvertebrates encountered in the field) were significantly higher in the TZ compared to the RZ when 50% of streamflow was diverted. McClay (1968) and Rader and Belish (1999) reported similar findings for insects in streams in the western United States when flow was reduced to 75% and 40% of baseflow, respectively. Both studies suggested several possible explanations, including the immigration of insects from exposed areas. Although possible in our study, the minor reduction in total surface area at 50% flow reduction suggests that little area was exposed, thus reducing the propensity for immigration. Rader and Belish (1999) also suggested that an increase in water temperature in the dewatered zone in one of their study streams created more favorable conditions for invertebrate growth and development, in turn causing increased densities. This is also unlikely in our study, as Nuhfer and Baker (2004) reported a substantial increase in the rate of water warming 600 m downstream of the water diversion structure when 75% or more of the flow was diverted, but only minor differences in temperature at 50% flow reduction. Moreover, the riffle sampled in the TZ was only about 130 m downstream from the water diversion structure so warming would have been much less.

Our findings build upon the results of Baker and Coon (1995b). They noted that although total benthic macroinvertebrate density in Hunt Creek did not decline as a result of a 50% reduction in baseflow in the TZ, the PHABSIM model indicated that reducing stream flow more than 50% would reduce WUA for all taxa and that WUA losses would be substantial. A PHABSIM analysis of brook trout habitat during the same time period that data were collected for this study indicated that brook trout WUA would not be substantially reduced by decreasing stream flow until the discharge was equal to nearly 0.09 m^3/s, nearly 20% of summer baseflow (Baker and Coon 1995a, Nuhfer and Baker 2004). These results suggest that important brook trout food resources are more vulnerable to dewatering than brook trout foraging or resting habitat (Baker and Coon 1995b). Reducing flow by 90% caused insect density in the TZ to drop below that in the RZ, which coincides with the predicted decrease in WUA for common insect taxa at high levels of dewatering. Such a reduction in food resources has the potential to adversely affect populations of salmonids such as brook trout.

The variation in the abundance of benthic macroinvertebrate taxa, particularly insects, at different levels of flow reduction may be partially explained by the feeding strategies and habitat preferences of the organisms. A large proportion of the insect taxa sampled from Hunt Creek were grazers and habitat generalists occupying both erosional and depositional habitats, such as Baetidae, Chironomidae, Elmidae adults and larvae, and Ephemerellidae.

The contribution of these benthic insect taxa to total insect abundance makes it difficult to confidently relate patterns in the abundance of other functional feeding groups, or habitat specialists, to the levels of flow reduction observed. Nevertheless, some general observations can be made, particularly with respect to habitat preference. For example, taxa preferring only erosional habitats and those classified as using both erosional and depositional habitats decreased in the TZ when 90% of flow was diverted but did not decrease in the RZ. Abundance of obligate depositional zone taxa did not change significantly in either zone, but these taxa were rare in both zones at all levels of flow.

To our knowledge, no other study has compared projections of WUA from a PHABSIM model to observed macroinvertebrate densities to test the assumption of a positive linear relation between WUA and benthic macroinvertebrate abundance. In general, we found that WUA was not linearly related to the density of the majority of the insect taxa modeled and that the relationships between density and WUA were variable. Although linear regressions of the density of Heptageniidae, Empididae, and Baetidae were significantly related to WUA, their density varied widely at normal flow and at a 50% reduction in flow. The density of obligate erosional taxa and erosional or depositional taxa was generally less variable at the lowest flow tested (90% reduction). Conversely, the density of predators such as Perlodidae and shredders such as Tipulidae was variable at all flows and exhibited no relation to estimates of WUA.

The between-observation variation in insect abundance that occurred when equal percentages of summer flow were diverted indicates that factors other than streamflow volume were affecting population dynamics in Hunt Creek. In addition, patterns of density in the RZ paralleled patterns of density in the TZ in certain cases, suggesting that upstream-downstream effects (i.e., connectivity) and/or larger-scale environmental or biotic factors were acting on observed trends in abundance rather than reduced flow. Kohler and Wiley (1997) reported that *Glossosoma* populations in many Michigan trout streams, including Hunt Creek, have collapsed due to recurrent pathogen outbreaks. These declines of *Glossosoma* were associated with large increases in periphyton and the abundance of most other grazer and filter-feeder taxa. In Hunt Creek, *Glossosoma* populations in the RZ declined dramatically after 1994 (Kohler and Wiley 1997). Data collected during our study indicate that a similar decline in *Glossosoma* occurred in the TZ after 1994. Thus, the generally poor relations between WUA and density of various grazer and filter feeding taxa were partially due to the strong effects of the *Glossosoma* population collapse on the overall invertebrate community.

If the assumption that WUA is positively related to benthic insect abundance is correct, then it is possible that the estimates of WUA from Baker and Coon (1995b) were inaccurate for many of the taxa modeled. Baker and Coon (1995b) made velocity, depth, and substrate measurements at 240 locations distributed across 7 transects in the TZ to generate WUA estimates for 13 benthic insect families. However, Railsback (1999) and Kondolf et al. (2000) noted that the location and numbers of transects used for habitat sampling exert great influence on WUA predictions. Accordingly, Nuhfer and Baker (2004) used 1,339 locations distributed along 63 transects to generate estimates of WUA for brook trout and found poor correlation between WUA predictions and brook trout abundance and survival rates. They suggested that if their efforts were insufficient to characterize brook trout habitat in the 600 m TZ, then the labor required for accurate projections of WUA would be prohibitive for most resource agencies. Although the extent of the habitat data collected by Nuhfer and Baker (2004) for projecting brook trout WUA was considerably larger than the data used by Baker and Coon (1995b) for benthic invertebrates, we also suggest that the effort required for accurately predicting suitable benthic invertebrate WUA is too labor intensive to be practical. This seems especially true when one considers the lack of consistent relationships between WUA and invertebrate abundance observed in this study.

It is necessary to acknowledge other limitations of our study. Baker and Coon (1995b) recognized that they probably did not adequately sample the first and second instars of many of the taxa in Hunt Creek because of the mesh size used on the Hess sampler, which also

applies to our 1997 and 1998 data that were collected using the same protocols. However, Baker and Coon (1995b) suggested that it is unlikely that sampling the early instars would have influenced the results of their study because the direction of predicted changes in WUA (increases or decreases) generally matched the direction of observed changes in the density of insects. Assuming the model predictions are accurate, the same can be said of our 1997 and 1998 data, as the density of most insects did decline at 90% flow reduction as predicted by overall decreases in projected WUA.

We were also unable to compare WUA projections from PHABSIM analysis with the abundance of insect families that occurred in less than 20% or more than 80% of the samples collected by Baker and Coon (1995b), as we used their model predictions rather than constructing our own. Using PHABSIM to predict changes in WUA for infrequently occurring taxa would require a modification of the sampling protocols to more effectively sample those taxa (Baker and Coon 1995b), as Bovee (1986) noted that HSC constructed for small sample sizes are generally not representative of the habitat suitability requirements of the taxa. Care should also be taken in using PHABSIM to predict the effects of streamflow alterations on frequently occurring taxa. Because most microhabitats are suitable for frequently occurring taxa, HSC for those taxa would be too general to be useful as a predictor of habitat change (Baker and Coon 1995b).

Another important note is that the results presented in this study are unique to Hunt Creek under the levels of flow reduction studied and should not be considered widely applicable to all streams throughout Michigan or the Great Lakes region. We lacked replicated observations of benthic macroinvertebrate abundance at baseflow conditions throughout the entire summer season in years before flow reductions were initiated. Thus, we were limited to data collected prior to June 1 to represent baseflow conditions in the TZ. However, we did have data from an unimpaired, upstream control reach (i.e., the RZ) throughout the entire study. This makes the lack of pre-treatment data in the TZ only a minor concern. Also, we had only one season of data available for the 50% flow reduction, and we were unable to test the effect of other intermediate levels of flow reduction, such as a 75% reduction in baseflow, to determine its influence on benthic macroinvertebrate abundance. Hence, our conclusions are limited to moderate and extreme levels of flow reduction. Finally, a withdrawal of 50% of summer baseflow may have a more negative effect on the benthic macroinvertebrate community in marginal streams that do not have high-quality habitat under summer baseflow conditions.

Management Implications

Resource managers should consider the potential consequences of water withdrawals to all components of the aquatic community including benthic macroinvertebrates because such organisms are indicators of ecosystem health and an important link in food webs. The results presented in this study demonstrate that flow reductions can reduce the density of many benthic insect species, particularly filter feeding and grazing taxa, and those taxa that typically use erosional habitats. Although temperature was not directly observed in this study, Nuhfer and Baker (2004) noted a substantial increase in the rate of water warming downstream of the water diversion structure when 75% or more of the flow was diverted, which clearly has implications for coldwater stenothermic organisms such as benthic macroinvertebrates.

Managers should carefully consider the utility of the PHABSIM system in high-quality trout streams such as Hunt Creek, as we found generally insignificant relationships between WUA and benthic macroinvertebrate abundance. We observed a linear relationship between WUA projections from PHABSIM and the abundance of only two benthic insect families. Both of these relationships were variable, indicating that WUA alone is not an accurate predictor of insect abundance in a high-quality trout stream.

Further research is needed to test the utility of PHABSIM for predicting the response of the benthic macroinvertebrate community to water withdrawals across a wider range of flows and in other stream types, such as marginal streams

with habitat conditions that may be affected by flow reductions to a greater extent than Hunt Creek. Until this occurs, the results of this study and the labor-intensive PHABSIM technique should be applied with caution.

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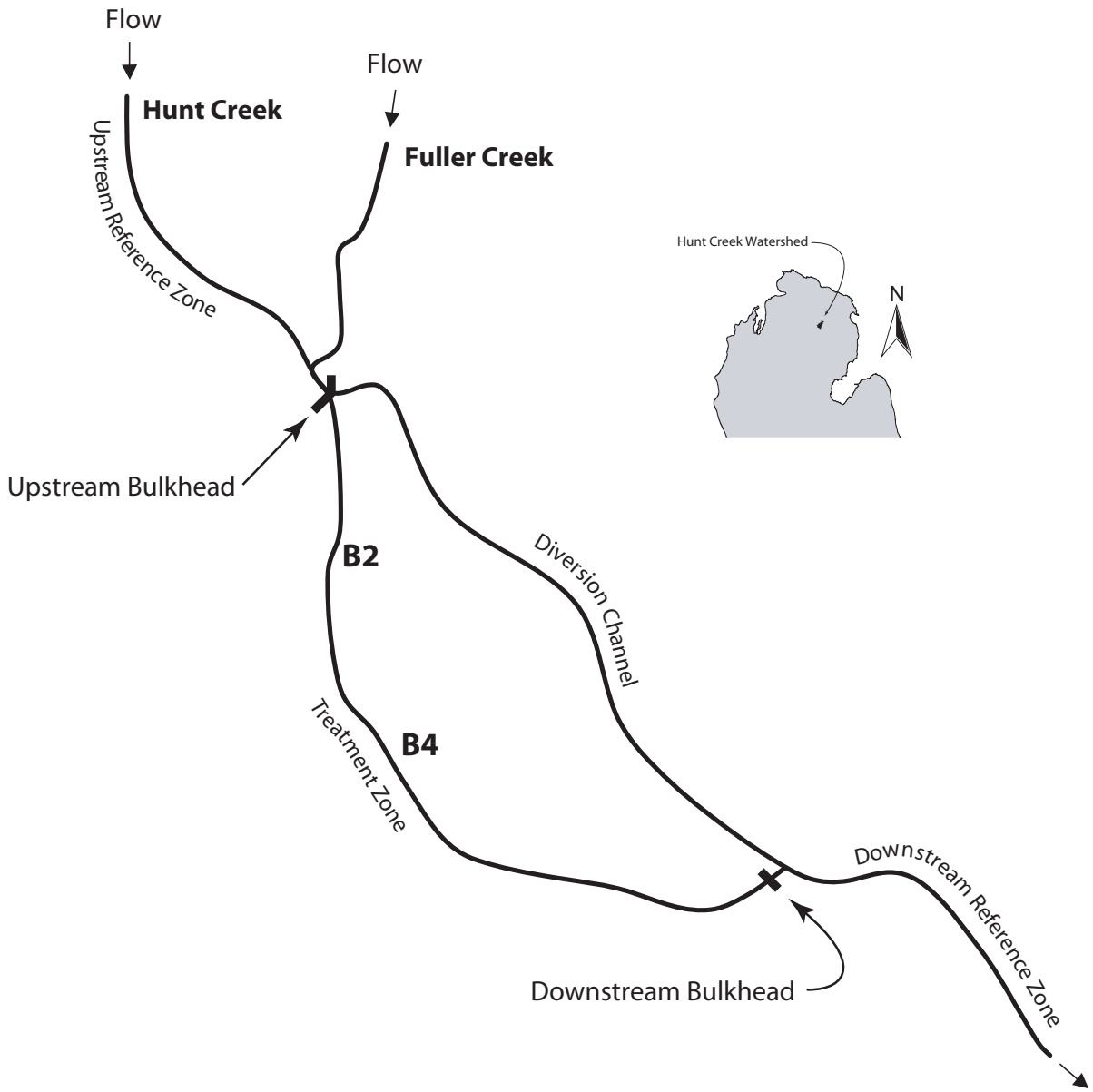

Figure 1.−Map of the Hunt Creek study area. The upstream bulkhead was the boundary between the upstream reference zone and the treatment zone. The downstream bulkhead was the boundary between the treatment zone and the downstream reference zone. Inset shows the position of the Hunt Creek watershed in the northeastern portion of Michigan's Lower Peninsula.

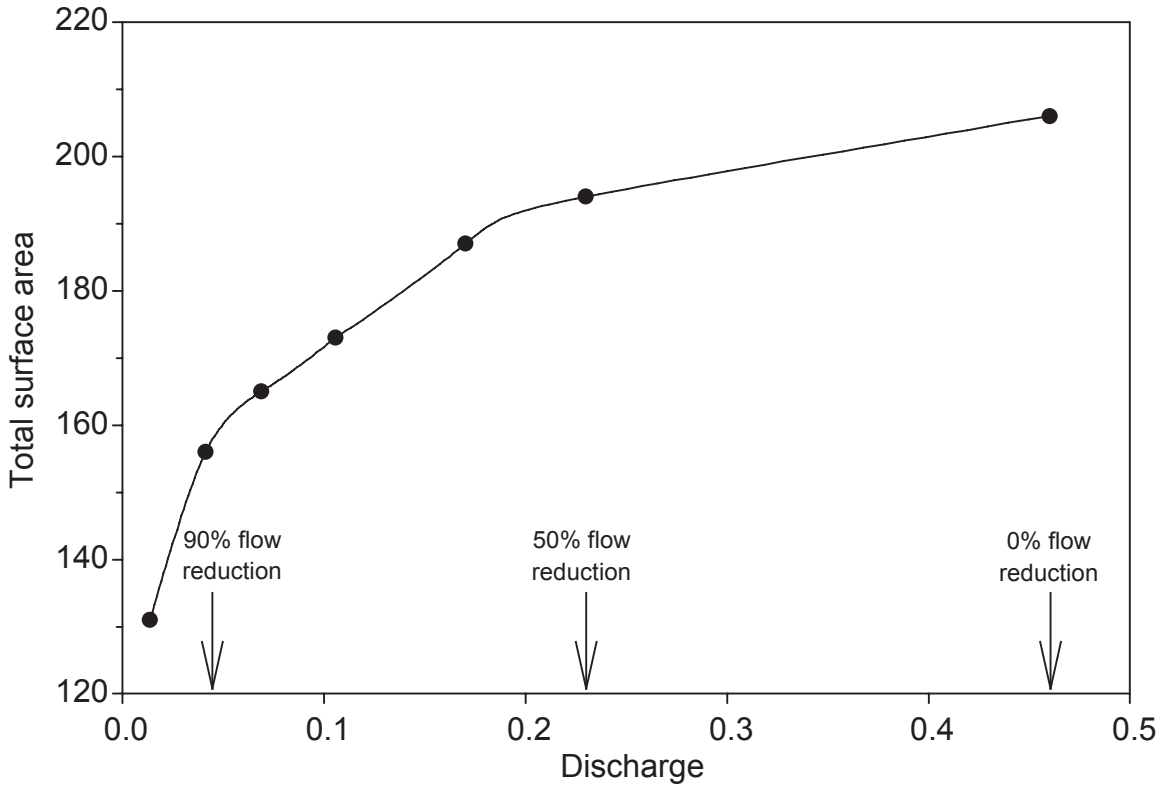

Figure 2.−Total surface area (m^2/100 m) as a function of discharge (m^3/s) for an experimentally dewatered treatment zone in Hunt Creek.

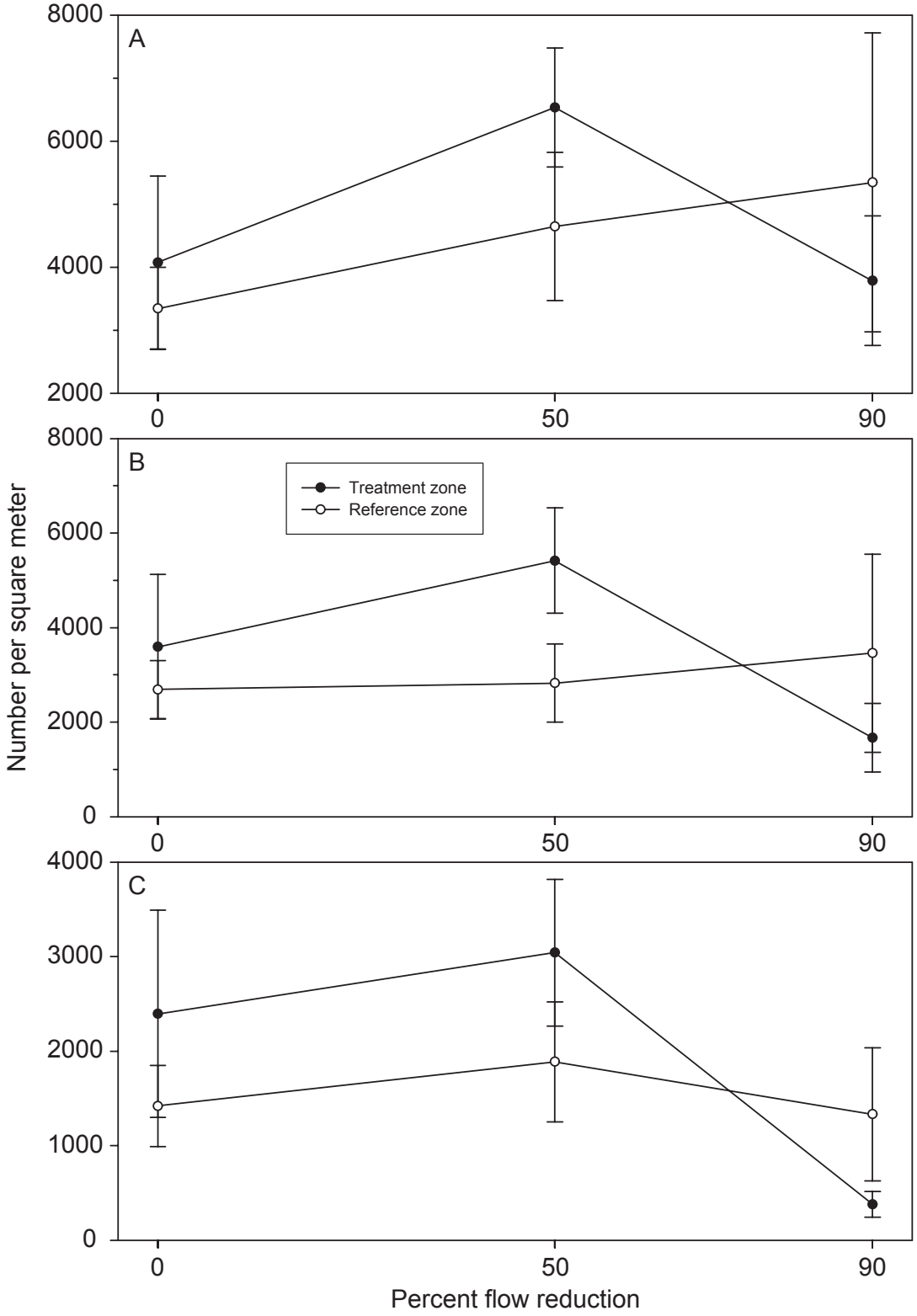

Figure 3.−Mean number of invertebrates (A), insects (B), and ephemeroptera, plectopera, and trichoptera taxa (C) per square meter (+/- 2 SE) in an experimentally dewatered treatment zone (TZ) and reference zone (RZ) in Hunt Creek. Summer discharge was reduced by 50% in 1994, and 90% in 1997 and 1998. Zero percent flow reduction represents summer discharge before water diversion was initiated in the TZ on June 1 of each year. Summer discharge in the RZ was not altered.

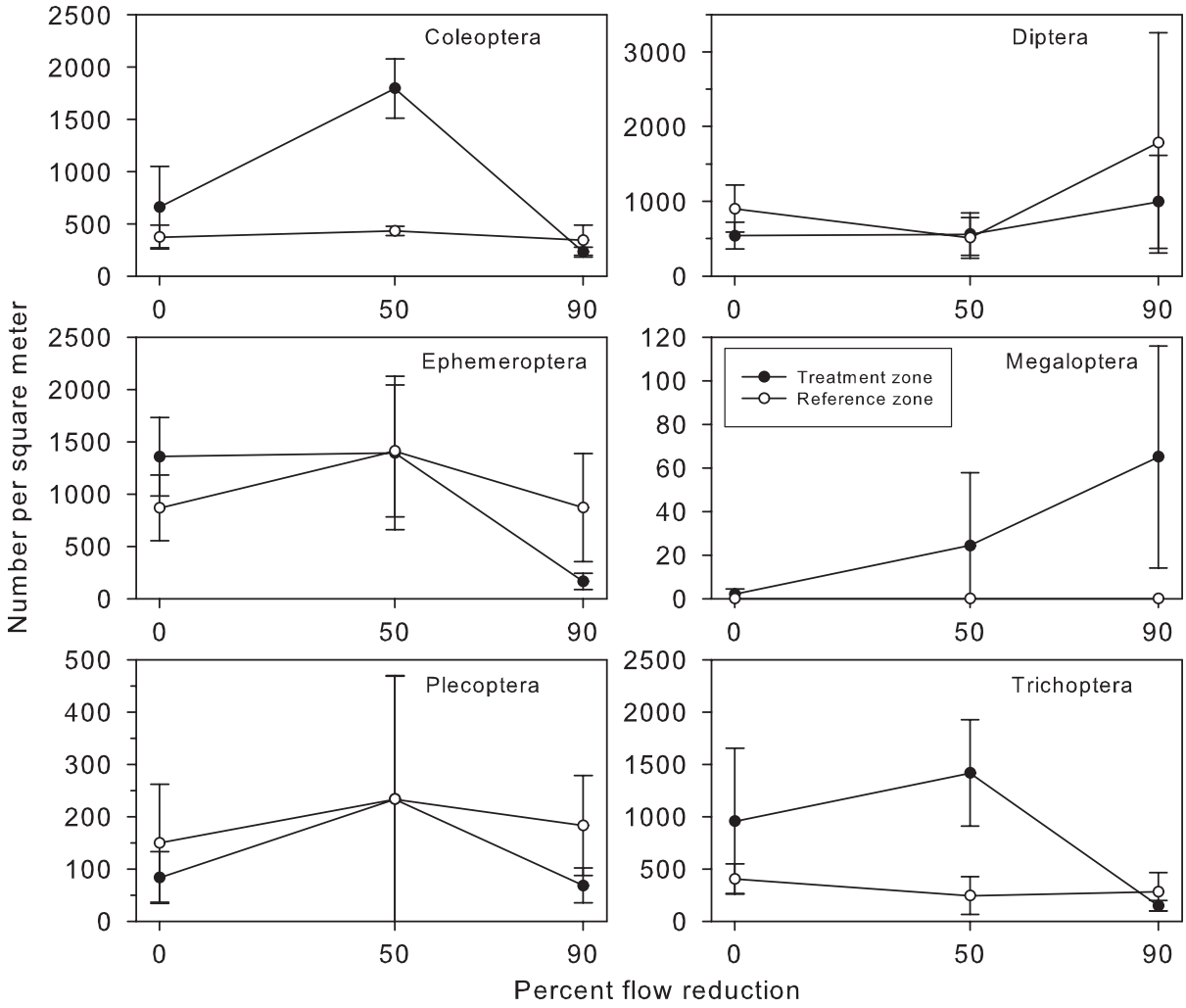

Figure 4.−Mean number of insects per square meter (+/- 2 SE) for select orders in an experimentally dewatered treatment zone (TZ) and reference zone (RZ) in Hunt Creek. Summer discharge was reduced by 50% in 1994, and 90% in 1997 and 1998. Zero percent flow reduction represents summer discharge before water diversion was initiated in the TZ on June 1 of each year. Summer discharge in the RZ was not altered.

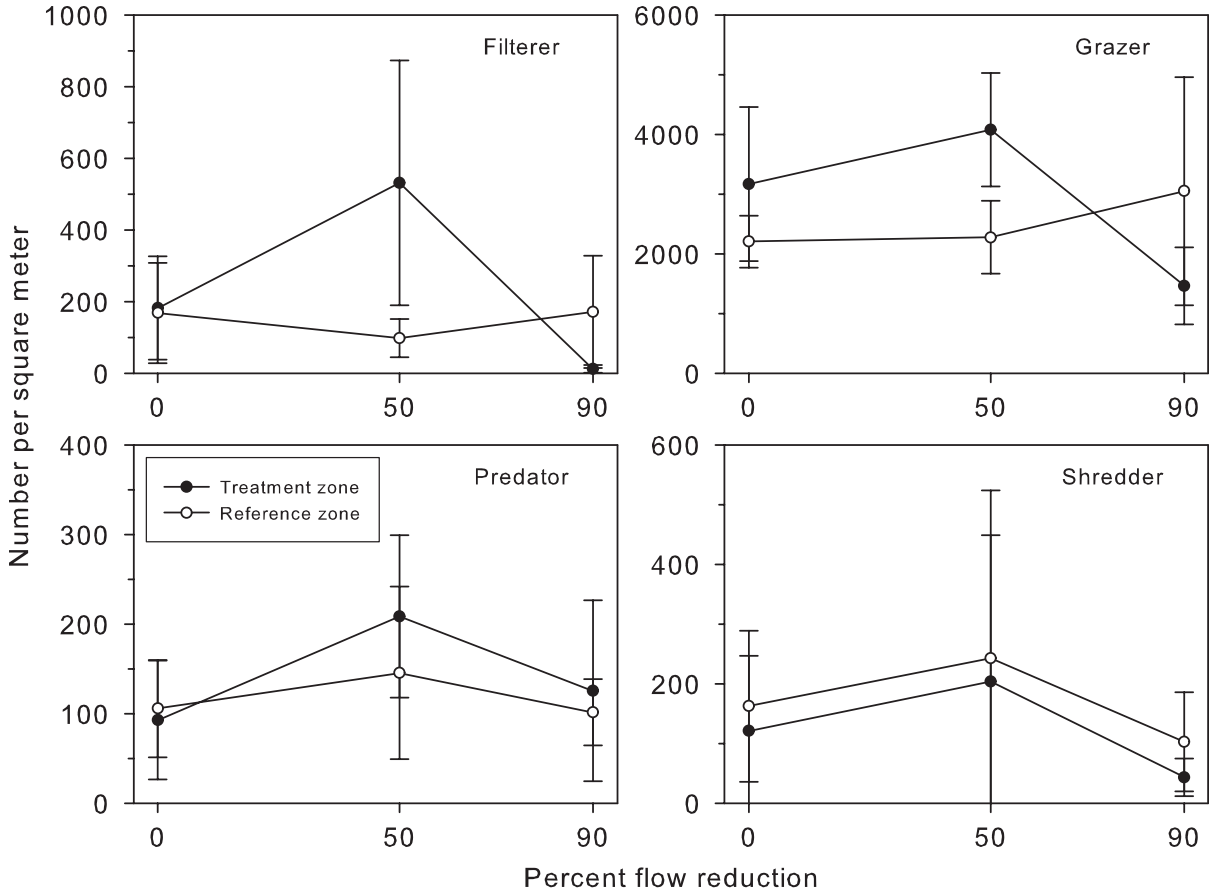

Figure 5.−Mean number of insects per square meter (+/- 2 SE) by functional feeding groups in an experimentally dewatered treatment zone (TZ) and reference zone (RZ) in Hunt Creek. Summer discharge was reduced by 50% in 1994, and 90% in 1997 and 1998. Zero percent flow reduction represents summer discharge before water diversion was initiated in the TZ on June 1 of each year. Summer discharge in the RZ was not altered.

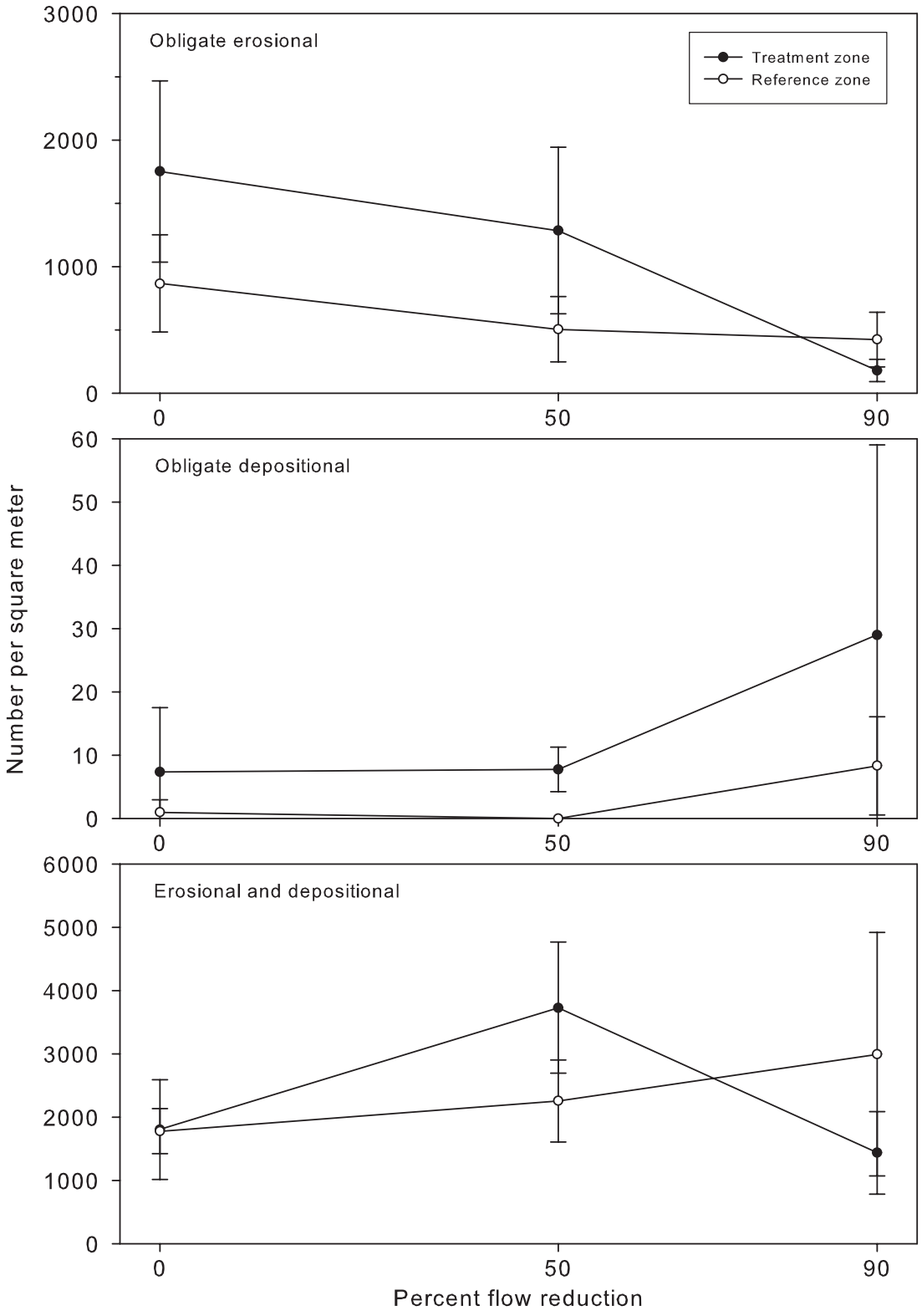

Figure 6.−Mean number of insects per square meter (+/- 2 SE) by habitat preference in an experimentally dewatered treatment zone (TZ) and reference zone (RZ) in Hunt Creek. Summer discharge was reduced by 50% in 1994, and 90% in 1997 and 1998. Zero percent flow reduction represents summer discharge before water diversion was initiated in the TZ on June 1 of each year. Summer discharge in the RZ was not altered.

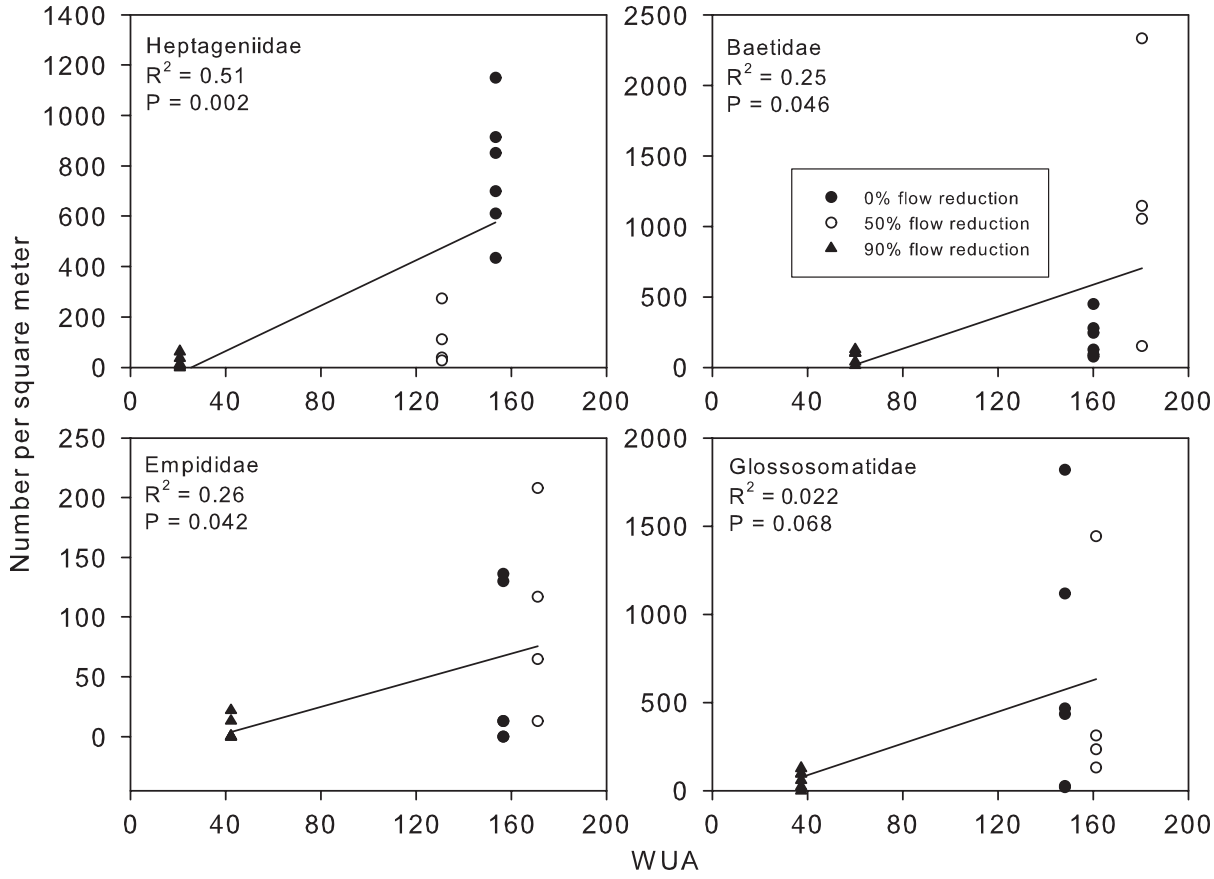

Figure 7.−Relation between abundance and weighted usable area (WUA, m^2/100 m) for select taxa in an experimentally dewatered treatment zone of Hunt Creek. Diamonds depict abundance during months when summer flow was normal, while squares and triangles show abundance during months when flow was diverted 50% and 90%, respectively.

Table 1.–Percent frequency of occurrence of invertebrate taxa in samples collected from a treatment (dewatered) zone and reference zone of Hunt Creek in April through August of 1994, 1997, and 1998. Taxa selected for habitat modeling are in bold face type.

			Percent occurrence		
Class	Order	Family	1994 (N = 83)	1997 (N = 70)	1998 (N = 68)
Insecta	Coleoptera	Dytiscidae	0.0	1.4	1.5
		Elmidae adult	84.3	40.0	35.3
		Elmidae larvae	98.8	85.7	80.9
		Undetermined	1.2	0.0	0.0
	Diptera	Athericidae	10.8	0.0	4.4
		Ceratopogonidae	6.0	2.9	25.0
		Chironomidae	86.7	98.6	95.6
		Empididae	68.7	21.4	35.3
		Muscidae	1.2	0.0	0.0
		Ptychopteridae	0.0	0.0	1.5
		Simuliidae	51.8	11.4	23.5
		Tabanidae	2.4	5.7	0.0
		Tipulidae	3.6	15.7	8.8
		Undetermined	45.8	1.4	0.0
	Ephemeroptera	**Baetidae**	97.6	82.9	91.2
		Ephemerellidae	53.0	55.7	51.5
		Heptageniidae	83.1	42.9	63.2
		Leptophlebiidae	2.4	0.0	4.4
		Undetermined	0.0	2.9	0.0
	Heteroptera	Gerridae	0.0	1.4	0.0
		Hydrometridae	0.0	1.4	0.0
	Megaloptera	Corydalidae	10.8	12.9	11.8
		Sialidae	0.0	1.4	0.0
	Odonata	Cordulegasteridae	1.2	0.0	0.0
		Gomphidae	0.0	0.0	1.5
	Plecoptera	Leuctridae	26.5	4.3	10.3
		Nemouridae	69.9	37.1	35.3
Insecta	Plecoptera	**Perlodidae**	32.5	34.3	30.9
		Undetermined	0.0	28.6	0.0
	Trichoptera	Brachycentridae	14.5	27.1	20.6
		Glossosomatidae	90.4	31.4	50.0
		Goeridae	0.0	21.4	10.3
		Hydropsychidae	47.0	21.4	13.2
		Hydroptilidae	4.8	4.3	11.8
		Lepidostomatidae	0.0	2.9	5.9
		Limnephilidae	33.7	8.6	2.9
		Philopotamidae	20.5	8.6	8.8
		Rhyacophilidae	53.0	24.3	47.1
		Uenoidae	0.0	34.3	51.5
		Undetermined	59.0	25.7	0.0

Table 1.–Continued.

Class	Order	Family	Percent occurrence 1994 (N = 83)	1997 (N = 70)	1998 (N = 68)
Arachnida	Acari	Hydrocarina	15.7	40.0	50.0
Bivalvia	Pelecypoda	Sphaeridae	0.0	4.3	1.5
	Unionoida	Unionidae	0.0	2.9	1.5
	Undetermined	Undetermined	0.0	1.4	1.5
Gastropoda	Bassomatophora	Physidae	0.0	2.9	5.9
Hirudinea	Undetermined	Undetermined	1.2	0.0	0.0
Malacostraca	Amphipoda	Gammaridae	97.6	90.0	94.1
	Isopoda	Asselidae	14.5	17.1	26.5
Oligochaeta	Lumbriculida	Lumbriculidae	0.0	8.6	13.2
	Undetermined	Undetermined	100.0	88.6	85.3
Turbellaria	Tricladida	Undetermined	1.2	1.4	4.4

Table 2.–Relation between computed weighted usable area (WUA, m^2/100 m) and discharge for 13 benthic macroinvertebrate families selected for habitat modeling in an experimentally dewatered treatment zone of Hunt Creek.

		Discharge (m^3/s)						
		0.01	0.04	0.07	0.11	0.17	0.23	0.46
		Percent flow reduction						
Order	Family	98	91	85	76	63	50	0
Coleoptera	Elmidae adult	3.4	16.6	35.5	65.0	111.0	141.3	147.3
Diptera	Ceratopogonidae	88.1	132.8	163.1	188.9	212.2	217.3	180.3
	Empididae	13.9	42.1	72.8	107.4	148.7	171.0	156.6
	Simulidae	4.7	29.6	65.7	108.7	153.0	175.8	169.2
	Tipulidae	30.8	66.0	99.7	135.8	173.8	192.2	157.4
Ephemeroptera	Baetidae	24.8	60.0	91.3	123.1	160.7	180.5	160.0
	Ephemerellidae	26.2	64.5	96.9	127.8	162.8	180.6	155.8
	Heptageniidae	6.7	20.8	35.9	59.1	99.2	130.7	153.4
Plecoptera	Nemouridae	29.8	77.0	115.1	148.4	180.2	193.1	164.7
	Perlodidae	9.1	36.2	68.6	104.8	145.3	166.6	165.4
Trichoptera	Glossosomatidae	11.0	37.4	66.2	97.8	138.1	161.2	148.0
	Hydropsychidae	5.2	24.7	50.6	85.7	130.9	155.1	147.8
	Rhyacophilidae	7.4	17.8	33.7	62.3	109.1	140.0	146.5

Table 3.–P-values from mixed-effect analysis of variance modeling the effects of stream section and level of flow reduction on benthic macroinvertebrate abundance in Hunt Creek. N refers to the total number of samples used in the analysis. EPT = Ephemeroptera, Plecoptera, and Trichoptera taxa. NS = not significant.

Metric	Source of variation	F	df	P
Total invertebrate abundance (N = 32)	Section	–	–	NS
	Flow	–	–	NS
	Section*Flow	5.42	2, 13	0.019
Total insect abundance (N = 32)	Section	–	–	NS
	Flow	–	–	NS
	Section*Flow	8.48	2, 13	0.004
Insect abundance by order (N = 256)	Order	512.09	7, 195	<0.001
	Section	9.23	1, 195	0.003
	Flow	–	–	NS
	Order*Section	8.44	7, 195	<0.001
	Order*Flow	5.01	14, 195	<0.001
	Section*Flow	4.42	2, 195	0.013
	Order*Section*Flow	3.15	14, 195	<0.001
EPT abundance (N = 32)	Section	–	–	NS
	Flow	6.84	2, 13	0.009
	Section*Flow	11.43	2, 13	0.001

Table 4.–P-values from Tukey's Honestly Significant Difference (HSD) multiple comparison tests evaluating mean differences (number/m^2) in the abundance of benthic macroinvertebrates among three levels of flow reduction in the treatment zone of Hunt Creek. No significant differences were found in the reference zone. N = 16 for all metrics. NS = not significant.

Metric	Comparison (% flow reduction)	Mean difference	HSD (q=3.73)	P
Total invertebrate abundance	50% vs. 0%	2457.75	2347.82	0.040
	90% vs. 0%	–	–	NS
	90% vs. 50%	-2750.42	2347.82	0.022
Total insect abundance	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	-3745.92	2121.25	0.003
Insect abundance by order				
Coleoptera	50% vs. 0%	1134.33	559.04	<0.001
	90% vs. 0%	–	–	NS
	90% vs. 50%	-1563.17	559.04	<0.001
Diptera	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Ephemeroptera	50% vs. 0%	–	–	NS
	90% vs. 0%	-1191.67	697.47	0.002
	90% vs. 50%	-1227.00	779.79	0.003
Heteroptera	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Megaloptera	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Odonata	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Plecoptera	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Trichoptera	50% vs. 0%	–	–	NS
	90% vs. 0%	-808.33	0.43[a]	0.002
	90% vs. 50%	-1269.58	0.49[a]	<0.001
EPT taxa abundance	50% vs. 0%	–	–	NS
	90% vs. 0%	-2015.50	1398.69	0.006
	90% vs. 50%	-2662.00	1563.78	0.002

[a]Reflects HSD between $\log_{10}$ transformed means used for statistical test.

Table 5.–P-values from mixed-effect analysis of variance modeling the effects of stream section and level of flow reduction on the abundance of functional feeding groups (filter feeder, grazer, predator or shredder) and habitat guilds (obligate erosional, obligate depositional, and erosional and depositional) in Hunt Creek. N refers to the total number of samples used in the analysis. NS = not significant.

Metric	Source of variation	F	df	P
Abundance by functional group (N = 128)	Group	124.76	3, 91	<0.001
	Section	–	–	NS
	Flow	5.28	2, 13	0.021
	Group*Section	–	–	NS
	Group*Flow	2.73	6, 91	0.018
	Section*Flow	11.04	2, 91	<0.001
	Group*Section*Flow	3.04	6, 91	0.009
Abundance by habitat guild (N = 96)	Guild	906.35	2, 65	<0.001
	Section	18.34	1, 65	<0.001
	Flow	–	–	NS
	Guild*Section	13.14	2, 65	<0.001
	Guild*Flow	21.12	4, 65	<0.001
	Section*Flow	7.75	2, 65	0.001
	Guild*Section*Flow	–	–	NS

Table 6.–P-values from Tukey's Honestly Significant Difference (HSD) multiple comparison tests evaluating mean differences (number/m^2) in the abundance of functional feeding groups (filter feeder, grazer, predator or shredder) and habitat guilds (obligate erosional, obligate depositional, and erosional and depositional) among three levels of flow reduction in the treatment zone of Hunt Creek. No significant differences were found in the reference zone. N = 16 for all metrics. NS = not significant.

Metric	Comparison (% flow reduction)	Mean difference	HSD (q=3.73)	P
Abundance by functional group				
Filter feeder	50% vs. 0%	–	–	NS
	90% vs. 0%	-170.33	0.81[a]	0.003
	90% vs. 50%	-519.33	0.90[a]	<0.001
Grazer	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	-2612.83	2023.55	0.012
Predator	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Shredder	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Abundance by habitat guild				
Obligate erosional	50% vs. 0%	–	–	NS
	90% vs. 0%	-1573.00	963.99	0.002
	90% vs. 50%	-1105.92	1077.78	0.044
Obligate depositional	50% vs. 0%	–	–	NS
	90% vs. 0%	–	–	NS
	90% vs. 50%	–	–	NS
Erosonial and depositional	50% vs. 0%	1924.92	1403.88	0.017
	90% vs. 0%	–	–	NS
	90% vs. 50%	-2292.42	1569.59	0.005

[a]Reflects HSD between $\log_{10}$ transformed means used for statistical test.

Table 7.–Statistics for simple linear regression models of the relationship between abundance and WUA for select insect families in an experimentally dewatered treatment zone of Hunt Creek. N refers to the total number of samples used in the analysis. NS=not significant.

Family	N	R^2	F	df	P
Baetidae	15	0.25	4.78	1, 14	0.046
Ceratopogonidae	15	0.09	–	–	NS
Elmidae adult	15	0.22	–	–	NS
Empididae	15	0.26	5.03	1, 14	0.042
Ephemerellidae	15	0.21	–	–	NS
Glossosomatidae	15	0.22	–	–	NS
Heptageniidae	15	0.51	14.62	1, 14	0.002
Hydropsychidae	15	0.22	–	–	NS
Nemouridae	15	0.19	–	–	NS
Perlodidae	15	0.00	–	–	NS
Rhyacophilidae	15	0.07	–	–	NS
Simulidae	15	0.14	–	–	NS
Tipulidae	15	0.01	–	–	NS

References

Alexander, G. R., and H. Gowing. 1976. Relationships between diet and growth in rainbow trout (*Salmo gairdneri*), brook trout (*Salvelinus fontinalis*), and brown trout (*Salmo trutta*). Michigan Department of Natural Resources, Fisheries Research Report 1841, Ann Arbor.

Alexander, G. R., and E. A. Hansen. 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management 6:9–23.

Allan, J. D. 1981. Determinants of diet of brook trout (*Salvelinus fontinalis*) in a mountain stream. Canadian Journal of Fisheries and Aquatic Sciences 38:184–192.

Anderson, R. O. 1959. A modified flotation technique for sorting bottom fauna samples. Limnology and Oceanography 4:198–206.

Baker, E. A., and T. G. Coon. 1995a. Comparison of predicted habitat change and brook trout population response to a simulated irrigation withdrawal in Hunt Creek, Michigan. Michigan Department of Natural Resources Fisheries Research Report 2018, Ann Arbor.

Baker, E. A., and T. G. Coon. 1995b. Comparison of predicted habitat change and benthic macroinvertebrate response to a simulated irrigation withdrawal in Hunt Creek, Michigan. Michigan Department of Natural Resources Fisheries Research Report 2019, Ann Arbor.

Bechara, J. S., G. Moreau, and D. Planas. 1992. Top-down effects of brook trout (*Salvelinus fontinalis*) in a boreal forest stream. Canadian Journal of Fisheries and Aquatic Sciences 49:2093–2103.

Boulton, A. J., and P. S. Lake. 1992. Stability of an aquatic macroinvertebrate community in a multiyear hydrologic disturbance regime. Ecology 73:2192–2207.

Bovee, K. D. 1985. Evaluation of the effects of hydropeaking on aquatic macroinvertebrates using PHABSIM. Pages 236–241 *in* Olson, F. W., R. G. White, and R. H. Hamre, editors. Proceedings of the symposium of small hydropower and fisheries. American Fisheries Society, Bethesda, Maryland.

Bovee, K. D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U. S. Fish and Wildlife Service Biological Report 86(7), Washington, D.C.

Bovee, K. D., T. J. Newcomb, and T. G. Coon. 1994. Relations between habitat variability and population dynamics of bass in the Huron River, Michigan. U.S. Geological Survey, Biological Report 21, Washington, D.C.

Castella, E., M. Bickerton, P. D. Armitage, and G. E. Petts. 1995. The effects of water abstraction on invertebrate communities in UK streams. Hydrobiologia 308:167–182.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. The American Naturalist 100 (913):345–357.

Cobb, D. G., T. D. Galloway, and J. F. Flannagan. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Canadian Journal of Fisheries and Aquatic Sciences 49:1788–1795.

Dorr, J. A. Jr., and D. F. Eschman. 1970. Geology of Michigan. The University of Michigan Press, Ann Arbor.

Dudgeon, D. 1992. Effects of water transfer on aquatic insects in a stream in Hong Kong. Regulated Rivers: Research and Management 7:369–377.

Elliott, J. M. 1973. The food of brown and rainbow trout (*Salmo trutta* and *S. gairdneri*) in relation to the abundance of drifting invertebrates in a mountain stream. Oecologia 12:329–347.

Gore, J. A., and R. D. Judy, Jr. 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. Canadian Journal of Fisheries and Aquatic Sciences 38:1363–1370.

Gore, J. A. 1989. Models for predicting benthic macroinvertebrate habitat suitability under regulated flows. Pages 253–265 *in* Gore, J. A., and D. A. Petts, editors. Alternatives in Regulated River Management. CRC Press, Boca Raton, Florida.

Gowan, C. 1984. The impacts of irrigation withdrawals on brown trout (*Salmo trutta*) and two species of benthic macroinvertebrates in a typical southern Michigan stream. Master's thesis, Michigan State University, East Lansing.

Hilsenhoff, W. L. 1995. Aquatic insects of Wisconsin: Keys to Wisconsin genera and notes on biology, habitat, distribution, and species. Publication No. 3 of the Natural History Museums Council, University of Wisconsin, Madison.

Imbert, J. B., and J. A. Perry. 2000. Drift and benthic invertebrate responses to stepwise and abrupt increases in non-scouring flow. Hydrobiologia 436:191–208.

Kohler, S. L., and M. J. Wiley. 1997. Pathogen outbreaks reveal large-scale effects of competition in stream communities. Ecology 78:2164–2176.

Kondolf, F. M., E. W. Larsen, and J. G. Williams. 2000. Measuring and modeling the hydraulic environment for assessing instream flows. North American Journal of Fisheries Management 20:1016–1028.

McClay, W. 1968. Effects of controlled flow reductions on aquatic insects in a stream riffle. Master's thesis. Montana State University, Bozeman.

Merritt, R. W., and K. W. Cummins. 1984. An introduction to the aquatic insects of North America, second edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Merritt, R. W., and K. W. Cummins. 1996. An introduction to the aquatic insects of North America, third edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

Milhous, R. T., M. A. Updike, and D. M. Schneider. 1989. PHABSIM reference manual: version 2. U.S. Fish and Wildlife Service FWS/OBS 89/16. (Instream Flow Information Paper 26).

Nielsen, J. L. 1992. Microhabitat specific foraging behavior, diet, and growth of juvenile coho salmon. Transactions of the American Fisheries Society 121:617–634.

Nuhfer, A. J., and E. A. Baker. 2004. A field validation of the Instream Flow Incremental Methodology (IFIM) in a Michigan brook trout stream. Michigan Department of Natural Resources Fisheries Research Report 2068, Ann Arbor.

O'Keefe, J. H., and F. C. DeMoor. 1988. Changes in the physico-chemistry and benthic invertebrates of the Great Fish River, South Africa, following an interbasin transfer of water. Regulated Rivers: Research and Management 2:39–55.

Orth, D. J., and O. E. Maughan. 1983. Microhabitat preferences of benthic fauna in a woodland stream. Hydrobiologia 106:157–168.

Pennak, R. W. 1989. Freshwater invertebrates of the United States Protozoa to Mollusca, third edition. John Wiley and Sons, Inc. New York.

Rader, R. B., and T. A. Belish. 1999. Influence of mild to severe flow alterations on invertebrates in three mountain streams. Regulated Rivers: Research and Management 15:353–363.

Railsback, S. 1999. Reducing uncertainties in instream flow studies. Fisheries 24(4):24–26.

Reiser, D. W., T. A. Wesche, and C. Estes. 1989. Status of Instream Flow legislation and practices in North America. Fisheries 14(2):22–29.

SPSS Inc. 2002. SPSS Base User's Guide 11.5. SPSS Inc., Chicago, Illinois.

USDA (United States Department of Agriculture). 1999. 1997 Census of Agriculture, Michigan State and County Data, Volume 1, Geographic Area Series Part 22. Document AC97A–22, Washington D.C.

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Appendix A.–Benthic macroinvertebrate density estimates (number/m$^{2)}$, standard error estimates in parentheses, from one riffle each in a treatment (dewatered) zone and reference zone of Hunt Creek, 1994. TZ = treatment zone, RZ = reference zone.

				Date in 1994					
Class	Order	Family	Sec.	12-May	01-Jun	20-Jun	12-Jul	03-Aug	23-Aug
Insecta	Coleoptera	Dytiscidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Elmidae adult	TZ	377 (80)	214 (56)	273 (44)	149 (52)	299 (62)	390 (66)
			RZ	78 (32)	162 (65)	182 (65)	106 (46)	84 (27)	84 (51)
		Elmidae larvae	TZ	1078 (175)	675 (256)	1331 (323)	2019 (374)	1558 (373)	1149 (343)
			RZ	364 (68)	247 (54)	305 (111)	341 (73)	305 (51)	312 (159)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Diptera	Athericidae	TZ	6 (6)	19 (14)	6 (6)	19 (14)	13 (13)	13 (8)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ceratopogonidae	TZ	13 (13)	0 (0)	6 (6)	0 (0)	13 (8)	6 (6)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Chironomidae	TZ	468 (169)	123 (29)	234 (77)	364 (100)	558 (132)	117 (37)
			RZ	643 (149)	130 (34)	565 (264)	265 (140)	201 (89)	123 (54)
		Empididae	TZ	136 (49)	130 (55)	208 (70)	117 (28)	65 (34)	13 (8)
			RZ	149 (43)	136 (43)	227 (95)	98 (36)	97 (34)	32 (19)
		Muscidae	TZ	0 (0)	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ptychopteridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Tabanidae	TZ	13 (8)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Tipulidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	19 (14)	6 (6)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Simuliidae	TZ	52 (27)	32 (22)	6 (6)	104 (38)	156 (119)	32 (26)
			RZ	468 (250)	156 (80)	26 (26)	60 (19)	149 (72)	65 (40)
		Undetermined	TZ	6 (6)	6 (6)	6 (6)	45 (17)	65 (28)	39 (15)
			RZ	58 (16)	78 (22)	78 (29)	23 (16)	6 (6)	32 (13)

Appendix A.–Continued.

Class	Order	Family	Sec.	Date in 1994					
				12-May	01-Jun	20-Jun	12-Jul	03-Aug	23-Aug
	Ephemeroptera	Baetidae	TZ	448 (83)	91 (33)	149 (42)	1143 (218)	2331 (576)	1052 (210)
			RZ	759 (142)	442 (92)	545 (74)	992 (187)	2182 (389)	935 (215)
		Ephemerellidae	TZ	643 (55)	350 (78)	253 (33)	117 (41)	39 (21)	19 (14)
			RZ	58 (16)	26 (13)	13 (8)	0 (0)	13 (13)	0 (0)
		Heptageniidae	TZ	1149 (136)	851 (106)	273 (49)	110 (31)	39 (15)	26 (13)
			RZ	649 (106)	539 (83)	487 (62)	326 (84)	130 (30)	19 (13)
		Leptophlebiidae	TZ	0 (0)	0 (0)	13 (8)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Heteroptera	Gerridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Insecta	Heteroptera	Hydrometridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Megaloptera	Corydalidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	71 (17)	26 (14)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Sialidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Odonata	Cordulegasteridae	TZ	6 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Gomphidae	TZ	6 (6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Plecoptera	Leuctridae	TZ	0 (0)	45 (17)	104 (41)	6 (6)	45 (26)	13 (8)
			RZ	6 (6)	19 (14)	13 (8)	0 (0)	6 (6)	0 (0)
		Nemouridae	TZ	162 (47)	104 (32)	435 (90)	45 (24)	97 (44)	26 (13)
			RZ	117 (61)	162 (78)	539 (166)	159 (66)	104 (45)	19 (14)
		Perlodidae	TZ	6 (6)	0 (0)	26 (9)	0 (0)	97 (48)	39 (12)
			RZ	6 (6)	6 (6)	19 (9)	23 (16)	45 (24)	6 (6)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix A.–Continued.

Class	Order	Family	Sec.	Date in 1994					
				12-May	01-Jun	20-Jun	12-Jul	03-Aug	23-Aug
	Trichoptera	Brachycentridae	TZ	71 (57)	0 (0)	6 (6)	6 (6)	0 (0)	6 (6)
			RZ	6 (6)	26 (14)	19 (14)	0 (0)	0 (0)	0 (0)
		Glossosomatidae	TZ	1818 (483)	1117 (269)	1442 (263)	234 (73)	312 (38)	130 (47)
			RZ	571 (141)	253 (31)	221 (53)	76 (22)	65 (17)	84 (40)
		Goeridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Hydropsychidae	TZ	195 (55)	84 (50)	208 (67)	32 (13)	636 (148)	740 (180)
			RZ	6 (6)	6 (6)	0 (0)	0 (0)	13 (13)	26 (13)
		Hydroptilidae	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	39 (32)	0 (0)	13 (13)	0 (0)
		Lepidostomatidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Limnephilidae	TZ	247 (217)	39 (15)	26 (19)	13 (8)	6 (6)	0 (0)
			RZ	78 (34)	78 (22)	104 (58)	15 (10)	0 (0)	13 (13)
		Philopotamidae	TZ	0 (0)	19 (14)	84 (32)	32 (19)	13 (5)	65 (43)
			RZ	0 (0)	0 (0)	13 (13)	8 (8)	13 (5)	0 (0)
		Rhyacophilidae	TZ	52 (25)	13 (8)	52 (38)	13 (13)	136 (37)	52 (15)
			RZ	39 (15)	39 (6)	52 (15)	38 (18)	19 (9)	19 (9)
		Uenoidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Undetermined	TZ	123 (24)	39 (12)	344 (46)	838 (169)	175 (103)	58 (19)
			RZ	26 (14)	45 (26)	65 (37)	38 (25)	13 (8)	6 (6)
Arachnida	Acari	Hydrocarina	TZ	0 (0)	0 (0)	71 (37)	26 (14)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	78 (29)	53 (34)	0 (0)	0 (0)
Bivalvia	Pelecypoda	Sphaeriidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Unionoida	Unionidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix A.–Continued.

Class	Order	Family	Sec.	Date in 1994					
				12-May	01-Jun	20-Jun	12-Jul	03-Aug	23-Aug
Bivalvia	Undetermined	Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Gastropoda	Bassomatophora	Physidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Hirudinea	Undetermined	Undetermined	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Malacostraca	Amphipoda	Gammaridae	TZ	117 (36)	234 (84)	630 (196)	1506 (338)	753 (149)	1279 (264)
			RZ	760 (102)	429 (62)	903 (326)	992 (215)	2857 (497)	2364 (820)
	Isopoda	Asselidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	91 (24)	104 (68)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)	6 (6)
Oligochaeta	Lumbriculida	Lumbriculidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Undetermined	Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Turbellaria	Tricladida	Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Total	TZ	7186 (624)	4186 (419)	6198 (708)	6944 (596)	7587 (757)	5406 (530)
			RZ	4842 (400)	2979 (212)	4493 (707)	3614 (353)	6321 (648)	4145 (868)

Appendix B.–Benthic macroinvertebrate density estimates (number/m^2), standard error estimates in parentheses, from one riffle each in a treatment (dewatered) zone and reference zone of Hunt Creek, 1997. TZ=treatment zone, RZ=reference zone.

				Date in 1997				
Class	Order	Family	Sec.	29-Apr	29-May	26-Jun	1-Aug	29-Aug
Insecta	Coleoptera	Dytiscidae	TZ	0 (0)	0 (0)	0 (0)	6 (6)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Elmidae adult	TZ	19 (13)	107 (34)	50 (37)	82 (46)	107 (56)
			RZ	13 (8)	19 (13)	19 (9)	0 (0)	25 (19)
		Elmidae larvae	TZ	636 (290)	478 (99)	164 (55)	195 (74)	201 (69)
			RZ	503 (134)	453 (227)	340 (110)	220 (122)	654 (141)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Diptera	Athericidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ceratopogonidae	TZ	0 (0)	6 (6)	0 (0)	6 (6)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Chironomidae	TZ	812 (220)	472 (98)	220 (77)	654 (187)	315 (157)
			RZ	1259 (307)	957 (433)	919 (173)	289 (58)	535 (144)
		Empididae	TZ	0 (0)	13 (13)	0 (0)	0 (0)	0 (0)
			RZ	6 (6)	82 (51)	101 (50)	44 (24)	31 (25)
		Muscidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ptychopteridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Tabanidae	TZ	0 (0)	0 (0)	6 (6)	6 (6)	6 (6)
			RZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
		Tipulidae	TZ	25 (19)	13 (13)	0 (0)	0 (0)	25 (13)
			RZ	0 (0)	6 (6)	13 (8)	13 (8)	0 (0)
		Simuliidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	113 (80)	264 (154)	6 (6)	0 (0)
		Undetermined	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix B.–Continued.

Class	Order	Family	Sec.	Date in 1997				
				29-Apr	29-May	26-Jun	1-Aug	29-Aug
	Ephemeroptera	Baetidae	TZ	126 (30)	76 (27)	38 (15)	101 (13)	13 (8)
			RZ	132 (36)	132 (56)	334 (134)	963 (246)	510 (258)
		Ephemerellidae	TZ	365 (114)	365 (51)	69 (41)	13 (8)	13 (8)
			RZ	101 (25)	132 (49)	25 (19)	19 (13)	6 (6)
		Heptageniidae	TZ	610 (210)	913 (106)	13 (8)	6 (6)	0 (0)
			RZ	283 (121)	132 (36)	63 (56)	6 (6)	0 (0)
		Leptophlebiidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	6 (6)	6 (6)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Heteroptera	Gerridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Hydrometridae	TZ	0 (0)	6 (6)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Insecta	Megaloptera	Corydalidae	TZ	6 (6)	0 (0)	0 (0)	126 (55)	31 (21)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Sialidae	TZ	0 (0)	0 (0)	0 (0)	6 (6)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Odonata	Cordulegasteridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Gomphidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Plecoptera	Leuctridae	TZ	0 (0)	0 (0)	25 (25)	6 (6)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	6 (6)	0 (0)
		Nemouridae	TZ	50 (24)	25 (13)	31 (13)	0 (0)	0 (0)
			RZ	19 (13)	403 (199)	227 (96)	25 (25)	13 (8)
		Perlodidae	TZ	19 (9)	13 (8)	0 (0)	13 (8)	13 (8)
			RZ	31 (19)	6 (6)	38 (31)	63 (30)	120 (47)
		Undetermined	TZ	0 (0)	0 (0)	13 (8)	6 (6)	6 (6)
			RZ	0 (0)	0 (0)	38 (24)	19 (13)	25 (9)

Appendix B.–Continued.

Class	Order	Family	Sec.	Date in 1997				
				29-Apr	29-May	26-Jun	1-Aug	29-Aug
	Trichoptera	Brachycentridae	TZ	44 (37)	6 (6)	0 (0)	6 (6)	6 (6)
			RZ	25 (13)	44 (30)	19 (9)	13 (8)	19 (9)
		Glossosomatidae	TZ	434 (213)	466 (184)	94 (60)	0 (0)	94 (53)
			RZ	13 (8)	0 (0)	6 (6)	0 (0)	25 (25)
		Goeridae	TZ	6 (6)	6 (6)	0 (0)	31 (19)	50 (24)
			RZ	19 (13)	6 (6)	0 (0)	13 (8)	6 (6)
		Hydropsychidae	TZ	57 (43)	25 (13)	0 (0)	6 (6)	0 (0)
			RZ	6 (6)	44 (37)	13 (8)	13 (8)	6 (6)
		Hydroptilidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	25 (16)	13 (13)	0 (0)	0 (0)
		Lepidostomatidae	TZ	0 (0)	0 (0)	13 (8)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Limnephilidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	13 (8)
			RZ	0 (0)	6 (6)	13 (8)	0 (0)	6 (6)
		Philopotamidae	TZ	0 (0)	6 (6)	0 (0)	0 (0)	13 (8)
			RZ	0 (0)	13 (13)	25 (19)	0 (0)	0 (0)
		Rhyacophilidae	TZ	50 (18)	19 (9)	0 (0)	0 (0)	0 (0)
			RZ	38 (15)	44 (29)	19 (19)	0 (0)	31 (25)
		Uenoidae	TZ	170 (73)	120 (53)	13 (13)	0 (0)	0 (0)
			RZ	183 (26)	69 (42)	76 (34)	0 (0)	0 (0)
		Undetermined	TZ	0 (0)	6 (6)	38 (20)	31 (21)	0 (0)
			RZ	6 (6)	31 (25)	13 (8)	25 (19)	6 (6)
Arachnida	Acari	Hydrocarina	TZ	6 (6)	6 (6)	13 (13)	50 (20)	31 (16)
			RZ	6 (6)	19 (13)	82 (45)	82 (26)	94 (26)
Bivalvia	Pelecypoda	Sphaeriidae	TZ	0 (0)	13 (8)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)
	Unionoida	Unionidae	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
	Undetermined	Undetermined	TZ	0 (0)	0 (0)	0 (0)	13 (13)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix B.–Continued.

Class	Order	Family	Sec.	Date in 1997				
				29-Apr	29-May	26-Jun	1-Aug	29-Aug
Gastropoda	Bassomatophora	Physidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	19 (13)	0 (0)	0 (0)	0 (0)	0 (0)
Hirudinea	Undetermined	Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Malacostraca	Amphipoda	Gammaridae	TZ	157 (58)	220 (92)	1750 (944)	1724 (536)	736 (482)
			RZ	252 (48)	302 (194)	793 (425)	944 (174)	1800 (575)
Malacostraca	Isopoda	Asselidae	TZ	0 (0)	0 (0)	13 (8)	107 (51)	31 (25)
			RZ	0 (0)	6 (6)	6 (6)	0 (0)	19 (13)
Oligochaeta	Lumbriculida	Lumbriculidae	TZ	0 (0)	6 (6)	0 (0)	6 (6)	0 (0)
			RZ	13 (8)	25 (19)	0 (0)	0 (0)	0 (0)
	Undetermined	Undetermined	TZ	233 (72)	680 (224)	308 (159)	151 (64)	201 (117)
			RZ	541 (235)	201 (79)	1013 (374)	157 (44)	195 (25)
Turbellaria	Tricladida	Undetermined	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Total	TZ	3825 (505)	4066 (363)	2889 (967)	3357 (585)	1917 (533)
			RZ	3468 (434)	3270 (587)	4484 (652)	2920 (339)	4132 (666)

Appendix C.–Benthic macroinvertebrate density estimates (number/m^2), standard error estimates in parentheses, from one riffle each in a treatment (dewatered) zone and reference zone of Hunt Creek, 1998. TZ=treatment zone, RZ=reference zone.

				Date in 1998				
Class	Order	Family	Sec.	29-Apr*	19-May	26-Jun	27-Jul	21-Aug
Insecta	Coleoptera	Dytiscidae	TZ	0 (0)	0 (0)	0 (0)	7 (7)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Elmidae adult	TZ	6 (6)	44 (29)	31 (19)	37 (14)	73 (49)
			RZ	31 (13)	31 (16)	19 (13)	6 (6)	19 (13)
		Elmidae larvae	TZ	145 (47)	176 (46)	120 (64)	147 (45)	162 (39)
			RZ	201 (51)	138 (40)	321 (96)	233 (83)	201 (81)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Diptera	Athericidae	TZ	0 (0)	0 (0)	19 (13)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ceratopogonidae	TZ	6 (6)	0 (0)	13 (8)	15 (9)	95 (62)
			RZ	6 (6)	0 (0)	6 (6)	25 (9)	13 (8)
		Chironomidae	TZ	277 (58)	189 (64)	1101 (190)	1263 (139)	2144 (1686)
			RZ	535 (159)	491 (112)	950 (643)	4947 (3253)	2102 (1781)
		Empididae	TZ	0 (0)	13 (8)	13 (8)	0 (0)	22 (15)
			RZ	13 (13)	50 (15)	82 (28)	82 (32)	31 (21)
		Muscidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Ptychopteridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Tabanidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Tipulidae	TZ	0 (0)	13 (8)	0 (0)	7 (7)	22 (15)
			RZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
		Simuliidae	TZ	0 (0)	390 (383)	0 (0)	0 (0)	0 (0)
			RZ	25 (25)	31 (13)	50 (50)	183 (100)	13 (8)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix C.–Continued.

Class	Order	Family	Sec.	Date in 1998				
				29-Apr*	19-May	26-Jun	27-Jul	21-Aug
	Ephemeroptera	Baetidae	TZ	277 (86)	245 (54)	126 (56)	103 (54)	103 (42)
			RZ	629 (176)	491 (103)	258 (68)	2026 (601)	856 (186)
		Ephemerellidae	TZ	252 (72)	233 (56)	113 (50)	44 (20)	95 (33)
			RZ	25 (13)	25 (13)	0 (0)	0 (0)	31 (16)
		Heptageniidae	TZ	699 (249)	434 (113)	63 (42)	7 (7)	37 (18)
			RZ	340 (116)	296 (42)	76 (36)	19 (9)	13 (8)
		Leptophlebiidae	TZ	6 (6)	0 (0)	0 (0)	0 (0)	15 (15)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)
		Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Heteroptera	Gerridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Insecta	Heteroptera	Hydrometridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Megaloptera	Corydalidae	TZ	0 (0)	6 (6)	0 (0)	95 (50)	132 (66)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Sialidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Odonata	Cordulegasteridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Gomphidae	TZ	0 (0)	0 (0)	0 (0)	7 (7)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Plecoptera	Leuctridae	TZ	0 (0)	0 (0)	44 (21)	22 (15)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	6 (6)
		Nemouridae	TZ	38 (38)	19 (9)	63 (27)	15 (15)	7 (7)
			RZ	50 (20)	38 (18)	50 (50)	220 (206)	13 (8)
		Perlodidae	TZ	19 (13)	0 (0)	6 (6)	29 (22)	81 (21)
			RZ	13 (13)	6 (6)	0 (0)	107 (42)	88 (42)
		Undetermined	TZ	0 (0)	0 (0)	13 (8)	7 (7)	0 (0)
			RZ	0 (0)	13 (8)	13 (8)	25 (19)	0 (0)

Appendix C.–Continued.

Class	Order	Family	Sec.	Date in 1998				
				29-Apr*	19-May	26-Jun	27-Jul	21-Aug
	Trichoptera	Brachycentridae	TZ	13 (8)	44 (37)	0 (0)	0 (0)	29 (29)
			RZ	38 (26)	6 (6)	25 (13)	13 (8)	13 (13)
		Glossosomatidae	TZ	25 (9)	19 (9)	126 (60)	22 (10)	59 (42)
			RZ	44 (44)	6 (6)	239 (34)	101 (45)	107 (58)
		Goeridae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	76 (33)	13 (8)
		Hydropsychidae	TZ	19 (13)	38 (26)	0 (0)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	252 (237)	13 (13)
		Hydroptilidae	TZ	0 (0)	0 (0)	13 (8)	0 (0)	0 (0)
			RZ	0 (0)	13 (8)	31 (25)	113 (76)	0 (0)
		Lepidostomatidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	31 (19)
		Limnephilidae	TZ	0 (0)	0 (0)	0 (0)	7 (7)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	6 (6)	0 (0)
		Philopotamidae	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	38 (31)	44 (32)	6 (6)
		Rhyacophilidae	TZ	31 (8)	13 (8)	19 (9)	15 (15)	95 (42)
			RZ	19 (13)	13 (8)	50 (15)	50 (26)	38 (11)
		Uenoidae	TZ	176 (37)	120 (39)	25 (13)	22 (15)	0 (0)
			RZ	289 (113)	233 (51)	44 (17)	0 (0)	0 (0)
		Undetermined	TZ	0 (0)	0 (0)	6 (6)	7 (7)	0 (0)
			RZ	13 (8)	0 (0)	19 (13)	0 (0)	0 (0)
Arachnida	Acari	Hydrocarina	TZ	13 (8)	13 (8)	38 (18)	37 (24)	66 (34)
			RZ	38 (20)	57 (16)	31 (19)	94 (53)	82 (26)
Bivalvia	Pelecypoda	Sphaeriidae	TZ	0 (0)	6 (6)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Unionoida	Unionidae	TZ	0 (0)	0 (0)	0 (0)	0 (0)	7 (7)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Undetermined	Undetermined	TZ	0 (0)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Appendix C.–Continued.

Class	Order	Family	Sec.	Date in 1998				
				29-Apr*	19-May	26-Jun	27-Jul	21-Aug
Gastropoda	Bassomatophora	Physidae	TZ	0 (0)	0 (0)	0 (0)	7 (7)	7 (7)
			RZ	0 (0)	6 (6)	0 (0)	6 (6)	0 (0)
Hirudinea	Undetermined	Undetermined	TZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Malacostraca	Amphipoda	Gammaridae	TZ	120 (49)	233 (70)	1989 (383)	2606 (654)	1579 (543)
			RZ	453 (161)	466 (114)	843 (365)	1674 (887)	1844 (465)
	Isopoda	Asselidae	TZ	6 (6)	6 (6)	76 (34)	44 (28)	37 (21)
			RZ	0 (0)	0 (0)	13 (8)	31 (25)	13 (13)
Oligochaeta	Lumbriculida	Lumbriculidae	TZ	6 (6)	0 (0)	6 (6)	0 (0)	0 (0)
			RZ	6 (6)	19 (9)	19 (9)	0 (0)	0 (0)
	Undetermined	Undetermined	TZ	453 (147)	346 (148)	573 (200)	389 (104)	44 (16)
			RZ	214 (63)	107 (25)	730 (144)	673 (316)	63 (38)
Turbellaria	Tricladida	Undetermined	TZ	0 (0)	6 (6)	0 (0)	0 (0)	15 (9)
			RZ	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
		Total	TZ	2587 (328)	2606 (451)	4608 (492)	4961 (685)	4968 (1778)
			RZ	2982 (346)	2536 (211)	3913 (770)	11006 (3459)	5615 (1854)

*Samples from the RZ collected on 30-April.