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Structure and size distribution of benthic macroinvertebrate communities along a eutrophication gradient in streams of the Ottawa Valley.

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This work is dedicated to my brother, my guardian angel, who realized at an early age that life is made to be lived, that stress and worry need not be a part of it, and that winners lead and losers follow.

◆

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Abstract

The taxonomic composition and size structure of benthic macroinvertebrate assemblages from twelve streams were studied in relation to differences in trophic conditions. Orthocladiinae (Diptera: Chironomidae) were numerically dominant at 11 of the 12 sites, however the Hydropsychidae (Trichoptera) attained the highest biomass. Principal component analysis revealed differences in the composition of assemblages among rural and urban sites. Rural sites had higher densities of sensitive taxa such as Ephemeroptera, Chironominae and Simuliidae, while urban sites had higher densities of tolerant taxa such as Oligochaeta. Site scores on the first principal component, explaining the most taxonomic variability between regions, were significantly related to the nutrient differences between the rural and urban streams. The mean annual spectrum for the entire assemblage followed a unimodal distribution peaking at the 8 μg (dry mass) size class. Polynomial regression models fitted to the abundance per size class for the entire assemblage revealed a weak positive relationship with total phosphorus (TP). Subsequent analyses on the mean size spectra of seven dominant taxa revealed that the Oligochaeta and Hydroptilidae have significantly higher densities in the urban sites, which contain high TP, while the Ephemeroptera and Chironominae have significantly lower densities in these sites. The three other dominant taxa, including the Hydropsychidae, Tanypodinae and Orthocladiinae showed less obvious differences in densities per size class between regions. These results demonstrate that although the size spectra of the entire community may not be greatly influenced by differences in stream eutrophication, the spectra of certain key taxa do show responses of a higher magnitude. This discrepancy in detecting responses suggests that the size distribution of entire benthic assemblages is resilient to differences in stream productivity, despite significant changes in the taxonomic composition.

Résumé

La composition taxonomique et la structure en taille des ensembles de macroinvertébrés benthiques de douze ruisseaux ont été étudiées en fonction des différences d'état trophique entre sites. Les chironomides Orthocladiinae ont dominé numériquement dans 11 des 12 sites, et étaient surtout abondantes dans les ruisseaux de la région urbaine. L'analyse de composantes principales a démontré qu'il y avait des différences de composition taxonomique entre les sites urbains et ruraux. Les taxons sensible à la pollution, soient Ephemeroptera, Chironominae et Simuliidae étaient plus abondants dans les ruisseaux ruraux, tandis que les taxons tolérants aux conditions eutrophiques des ruisseaus urbains, tels les oligochètes, étaient plus abondants dans les ruisseaux urbains. La position des sites sur l'axe de la première composante principale, qui expliquait le plus de variabilité taxonomique entre les sites, était correlée aux différences de phosphore total, de seston et de périphyton entre les sites urbains et ruraux. Le spectre de taille moyen annuel de l'ensemble de tous les taxons suivait une distribution unimodale. La densité maximale se retrouvait dans la classe de taille de 8 µg de masse sèche. Les modèles de régression polynomiale ajustés à la densité par classe de taille de l'ensemble des taxons ont démontré que l'abondance était reliée de façon faible mais positive au phosphore total. Les analyses subséquentes des spectres de taille moyens annuels de 7 taxons dominants ont démontré que Oligochaeta et Hydroptilidae étaient plus abondants dans les sites urbains (là où la concentration de phosphore total est plus élevée), tandis que Ephemeroptera et Chironominae y étaient moins abondants. Les différences d'abondance de Hydropsychidae, Tanypodinae et Orthocladiinae entre les sites ruraux et urbains étaient moins évidentes. Ces résultats démontrent que les spectres de taille des ensembles de tous les taxons ne diffèrent peut-être pas assez pour démontrer l'influence des différences d'eutrophisation entre les sites, mais que les différences de densité par classe de taille pour certains taxons dominants le sont. Ces différences de réponse entre les spectres de l'ensemble et ceux des

taxons individuels suggère que la distribution en taille des ensembles d'invertébrés benthiques est résiliente aux différences de productivité des ruisseaux, malgré les changements significatifs de la composition taxonomique.

Introduction

The taxonomic composition and size structure of benthic invertebrate communities are determined by the differential sensitivity of the organisms to alterations of their habitat. Benthic invertebrates are affected by various biotic and abiotic factors. These include the quality and quantity of refugia and food sources, risk of predation, water chemistry, temperature and substrate characteristics (Resh and Rosenberg 1984; Lauritsen 1985; Allan 1995; Merritt and Cummins 1996). Habitat preferences and tolerance to changes in habitat features vary among taxa and can depend on life history, physiology and behavioral adaptations (Resh and Rosenberg 1984; Allan 1995; Merritt and Cummins 1996). Studies on the spatial and temporal variation of the taxonomic composition of benthic assemblages have proved useful and have become an integral part of many aquatic ecosystem assessments.

Over the past two decades, the focus of some of the research dealing with the structure of benthic invertebrate assemblages has shifted from a strictly taxonomic approach to characterizing the size structure of these assemblages. Size spectra research tantalized benthic ecologists not only because it was new; it also proved to be complementary to and more practical than the traditional taxonomic approach. Although generating the size distribution of a community is a time consuming task that requires the measurement of individual organism body lengths, it requires very little taxonomic expertise and is not as time consuming as fine taxonomic identification.

The size structure of aquatic communities has been studied for many trophic levels, including bacteria, algae, plankton, benthos, macrophytes and fish. It is an important aspect of community ecology, as predator-prey interactions (Mittelbach 1981; Merrick et al. 1992; Rodriguez et al. 1993), secondary productivity (Dermott 1988; Bourassa and Morin 1995), and sensitivity to stress (Kiffney and Clements 1996) are generally size-dependent. The notion that communities of aquatic organisms may be regulated by size-dependent processes was addressed by Kerr (1974) and Borgmann (1987) following a study of marine pelagic communities by Sheldon et al (1972) who reported remarkable regularities over a wide range of particle sizes. This extensive study pioneered size spectra research on planktonic communities (Sprules and Munawar 1986; Sprules et al 1991; Boudreau and Dickie 1992; Rodriguez et al. 1993), which in turn drew the attention of benthic ecologists. Research dealing with benthic size structure of communities that include macroinvertebrates has covered many types of aquatic systems, including marine habitats (Schwinghamer 1981), lentic littoral habitats (Hanson et al. 1989; Rasmussen 1993, Rodriguez and Magnan 1993) and lotic habitats (Morin and Nadon 1991; Cattaneo 1993; Bourassa and Morin 1995; Morin et al. 1995; Kiffney and Clements 1996). The most striking feature of benthic assemblage size structure is that the amount of biomass per size class is relatively constant throughout the spectrum for a given habitat, and among habitats of a given study. Although biomass per size class can vary with ecosystem productivity (Sprules and Munawar 1986; Morin et al. 1995; Bourassa and Morin 1995) and substrate composition (Bourassa and Morin 1995; Rodriguez and Magnan 1993), size structure appears to be less variable than taxonomic structure.

The regularity of size distributions of assemblages of benthic macroinvertebrates is surprising considering the obvious shifts in taxonomic composition along environmental gradients. For the overall size distribution to remain approximately constant while taxonomic composition changes, the taxa that disappear along an environmental gradient must be replaced by other organisms of the same size, or the size distribution of the remaining taxa must change to compensate. Our main objective was to compare the magnitude and direction of the responses of the size spectra of individual taxa to those of the entire communities in relation to the different levels of eutrophication. This is an exploratory approach that is not well documented for these communities, thus provides a new angle in describing benthic invertebrate community size structure.

Methods

Site Characteristics

Twelve streams in the Outaouais region (Eastern Ontario and Southwestern Québec) were chosen to represent the local range of trophic conditions along a eutrophication gradient. These streams were combined into three groups; Des Trembles, Green, Leamy and Sawmill Creeks were located in urbanized areas of Ottawa and Hull; Blackburn, Corriveau, Pélissier and Rainville Creeks were in suburban agricultural areas of the Outaouais; and Chelsea, La Pêche Sud, Renaud and Taylor Creeks were in Gatineau Park, a protected Federal Park in Québec. Tables 1 and 2 summarize the site characteristics and environmental parameters that were measured.

Field Sampling

Each stream was sampled 12 times at near monthly intervals from May 09 1990 to May 25 1991, except Pelissier and Renaud Creeks which were visited 11 times. Sampling consisted of randomly removing 8 rocks from the riffle zone of each site. This was done slowly to diminish potential dislodging of invertebrates as the rocks were removed from the underlying stream bed. Total surface area of the rocks ranged between 20-334 cm^2, with an average of 137 cm^2 and standard deviation of 57.

Once removed, each rock was stored in a Whirlpak plastic bag containing a measured volume of 95% ethanol sufficient to completely cover the rock. At the exact location of each rock, water depth and current velocity were noted, the latter measured with a Gurly/Pigmy current meter. Water samples were taken from each site at each date to measure total phosphorus (TP) concentrations (in acid washed glass tubes) and seston concentrations (in three 4.5 L plastic bottles). The density of forest canopy was obtained by visual estimation of the percent cover at each site in August 1990.

Laboratory Analyses

Total phosphorus concentrations were estimated by the acid Molybdate method (Strickland and Parsons 1968) after Potassium Persulfate digestions of the water samples (Menzel and Corwin 1965).

Total seston concentrations were estimated by filtering 0.5 to 2 litres of water in the three 4.5 L plastic bottles on pre-weighted Whatman GF/C fiberglass filters. Dry mass of the residual material on the filters was measured after 24 hour drying at 24°C.

Sestonic Chlorophyll *a* concentrations were obtained by spectrophotometry. The ethanol containing the 0.5 to 2 litres of water was filtered on Whatman GF/C filters and chlorophyll *a* was extracted in the dark over a 24 hour period using 95% ethanol (Ostrofsky and Rigler 1987).

The periphyton biomass on each rock was estimated from the chlorophyll *a* extracted by the ethanol in the sampling bags which contained each individual rock. The extraction was done over a 24 hour period, at which time a 12 mL aliquot of ethanol was centrifuged and analyzed spectrophotometrically using the method of Ostrofsky and Rigler (1987).

The total surface area of each rock was calculated by wrapping the rock in aluminium foil and converting the weight of the aluminium into total surface area. The conversion factor was obtained from a calibration curve that is based on the weight of aluminum foil required to completely cover calibrated objects (Morin and Peters 1988).

All invertebrates, algae and debris attached to each rock were removed and rinsed over a 63 μm wet seive. Material retained by the seive was preserved in 95% ethanol and stored in plastic containers. For each of the 12 sites and each of the 12 dates sampled, four rocks were randomly selected of the eight replicate samples collected in the field. Samples that appeared to contain more than 200 organisms were wet seived a second time over two nested seives of 1 mm and 63 μm respectively. The entire fraction retained by the 1 mm seive was sorted and identified, while the remaining portion of the sample contained on the 63 μm seive was subsampled using a Folsom plankton splitter until the sample appeared to contain 50 to 200 organisms. Taxonomic identification was done using dissecting microscopes and taxonomic keys. The majority of insect groups were represented by immature larvae, which cause problems in the accuracy of identification, therefore most groups were only classified into Families (Appendix 1).

The body length of each invertebrate was measured using an image analysis system. Lengths were estimated by drawing a series of connecting vectors along the central axis of the body of the specimen which was projected from a dissecting microscope onto a monitor. The sum vector lengths were converted to millimeters and recorded. These body lengths were then used to estimate individual dry mass (µg) using the equation $M=aL^b$ where M is the dry mass (µg) of the invertebrate, L is the body length (in mm) and *a* and *b* are constants that were calculated for various taxonomic groups. Appendix 1 lists the coefficients used for each taxonomic group.

The density of invertebrates in each sample was calculated by dividing the number of animals of a given taxon by the surface area of the sampled rock. Individuals were then grouped into successive logarithmic size classes which upper limits increase by a factor of 2. The size spectra generated consist of the average annual logdensity of organisms, either total community or individual taxa / m^2 per size class.

Statistical Analyses

The annual average densities over the 12 sampling dates were used for all analyses due to low monthly sample sizes of individual taxa. Prior to calculating the average invertebrate densities, the data was transformed to stabilize the variance among samples. The transformation used was $\log_{10}$ (density + 1). The constant 1 was added to allow the logtransformation of zero individuals, which was a frequent occurrence for rare taxa and for many taxa during the winter months. Relative density and biomass were calculated for each region by calculating the means of each taxon in each region for the 8 rural and 4 urban sites, and expressing them as a percentage of the total for that region.

The average annual densities were used to conduct a principal component analysis (pca) describing the principal axes of variability in taxonomic composition. Pca was also used to compare the streams based on the environmental parameters. The first two components of the pca based on taxonomic composition were then correlated with environmental parameters to see if the taxonomic variability could be related to them. Multiple regression models were tried as well, but statistical problems were encountered due to the multicollinearity of total phosphorus, seston and periphyton.

The effect of environmental factors on the average densities in each size class were tested using polynomial regression analyses. Basic models to predict the size spectra of the entire assemblages and for the subsequent analyses done on the individual size spectra of dominant taxa included first, second and third order terms describing the relationship between density and body mass exclusively. The remaining environmental variables as well as first and second order interaction terms which account for size-dependent effects (ex. W x TP, W x TP^2) were then added to produce a complete model. Backward stepwise elimination was then used to determine which terms significantly affect the predictive power of the model. Comparison of the residual mean square values for the basic and complete models using the F-statistic (α=0.05) and of the difference between R^2 values of the basic and complete models were used to evaluate the degree to which the additional terms in the complete models improved precision.

Results

Nutrient and periphyton standing stock

The gradient of water chemistry and periphyton standing stock was unevenly covered by our twelve sites. The four streams located in the Ottawa-Hull region (urban sites) are characterized by eutrophic conditions (mean TP = 75µg / L, SE = 5.7; mean periphyton = 77 mg chl a / m^2, SE = 14), whereas the eight remaining streams from the Outaouais and Gatineau Park (rural sites) are characterized by meso-oligotrophic conditions (mean TP = 14 µg / L, SE = 0.9; periphyton 7.9 mg chl a / m^2, SE = 8.2) (Table 2). Principal component analysis using all environmental parameters indicated that 44% of the variability between among sites was related to TP, seston and periphyton. The sites were therefore divided into two groups, rural and urban, rather than collectively representing a gradient.

Total phosphorus, seston and periphyton were strongly correlated (Table 3). Consequently, regression analyses were done with each variable separately to avoid problems associated with multicollinearity. Here we only report the results of the size spectra analyses as a function of TP because it is the nutrient most often reported as a proxy for productivity in aquatic systems, and it is easily sampled and measured. The models presented in Tables 6 and 7 were also tested by replacing total phosphorus with seston and periphyton separately, revealing similar patterns.

Taxonomic composition of invertebrate assemblages

The invertebrates were classified into 35 taxonomic groups ranging from family to species. Mean annual average densities ranged from 5800 individuals / m^2 in Blackburn Creek to 32 630 individuals / m^2 in Leamy Creek. The annual average densities in the rural and urban regions were 11 647 individuals / m^2 and 30 273 individuals / m^2 respectively. Over the 12 sampling dates, average densities overall were lowest in April 1991 immediately after spring runoff (3067 individuals / m^2) and highest in June 1991 (42 253 individuals / m^2). Larvae of the Diptera sub-family Orthocladiinae achieved the highest density all sites except Pelissier Creek, where they co-dominated with Ephemeroptera. Most taxa were present in low densities: 95% of the total density consists of seven taxa in the rural sites and three taxa in the urban sites (Figure 1). The Trichoptera larvae Hydropsychidae, which were among the largest of all macroinvertebrates sampled, represented the highest proportion of total biomass in both the rural and urban streams (Figure 1). Taxa richness at each site was variable over the 12 sampling dates. Mean taxa richness for all sites was lowest in April and highest in October, but these values only ranged from 8 to 15 taxa. Average annual richness at each site ranged from 8 taxa in Sawmill Creek to 17 taxa in Pelissier Creek.

The assemblages from the rural and urban sites have different taxonomic compositions, as illustrated in Figure 2. The two main axes generated by the principal component analysis explain 47% of the variability within the data set, aggregating sites that are characterized by similar taxonomic compositions. The two main clusters that are illustrated in Figure 2 correspond to the rural and urban regions. Sawmill Creek and Taylor Creek seem to be unique in their taxonomic composition, as they are not grouped with the rest of the sites in their respective group. The relative densities of Isopoda and Simuliidae were higher in Sawmill Creek than in the other urban sites, and the densities of Simuliidae and Amphipoda were higher in Taylor Creek than in the other rural sites. These taxa obtained the highest negative loadings on the factor 2 axis (Figure 2).

Correlations between taxonomic composition and environmental parameters

Taxonomic composition, described by the scores of each site on the first principal component, was correlated to site characteristics. Scores on the first principal component factor were significantly related to total phosphorus, seston and periphyton in independent regression analyses, and to the first principal component factor of the pca using environmental parameters (Table 5). The strongest relationship occurred with total phosphorus, which was the parameter that differed the most between the rural and urban sites (Table 2). The second principal component factor illustrated the differences in taxonomic composition of Sawmill and Taylor creeks in relation to their respective groups, but was not significantly related to environmental parameters (Figure 2; Table 4).

Responses of taxa to environmental parameters

The densities of Orthocladiinae, Oligochaeta and Physidae were positively correlated to nutrient, seston and periphyton concentrations, whereas Glossomatidae and Limnephilidae showed a negative response to these three parameters (Table 5; Figure 3). Negative effects of total phosphorus and seston were indicated by the lower densities of Chironominae, Ephemeroptera and Philopotamidae in urban sites. Densities of Hydropsychidae and Hydroptilidae did not vary in relation to these nutrient differences.

Analysis of the size spectra of the entire assemblages

The mean annual spectra for assemblages of the rural and urban sites were of similar shape but differed in taxonomic composition and density for the larger size classes. The invertebrates covered a range of 24 logarithmic size classes overall, from the smallest Orthocladiinae and Ephemeroptera weighing 0.03 µg to the large Anisoptera weighing 262 155 µg. Invertebrates in the 8 µg size class were of the highest density overall (Figure 4). Most taxa were found in consecutive size classes, and those that were not likely consist of more than one dominant species. The Trichoptera family Psychomyiidae was one of the rare taxa, spanning the smallest range of size classes from 8 to 32 µg dry weight, while the Plecoptera covered 20 size classes ranging from 0.25 to 131 072 µg dry weight.

The mean annual density of organisms larger than 2 µg was higher in urban sites (Figure 4). The rural spectrum contained 24 size classes while the urban spectrum contained 21 size classes. The highest number of taxa per size class occurred in the rural spectrum, especially in the middle range, however many of these taxa collectively represented approximately 1% of their respective size class. Although the general shape of the total size spectrum for the rural region was similar to the spectrum of the urban region, the taxa that dominated the small, intermediate and large size classes were different (Figure 5). The small size classes of the urban spectrum were highly dominated by oligochaetes, while this portion of the rural spectrum contained a wider variety of taxa, of which the Ephemeroptera predominated. The intermediate size classes in both spectra were dominated by Orthocladiinae, although the rural spectrum also contained more Chironominae and Simuliidae than the urban spectrum. Hydropsychidae clearly dominated the largest size classes in both spectra. Most of the biomass in these assemblages consisted of the same taxa in the small, intermediate and large size classes, however the relative biomass of Chironominae in rural sites was more important than their density in the intermediate size classes. The relative biomass of Orthocladiinae was thus lower than their densities in the rural sites, as both Chironominae and Orthocladiinae are found in the intermediate size classes (Figure 5).

Density per size class for the mean annual spectrum of the entire assemblage was not significantly related to the environmental parameters measured. Stepwise regression revealed that total phosphorus, chlorophyll *a* and water temperature were significant predictors of density, but further analyses using the F-statistic to compare the residual mean square values for the models in Table 6 indicated that the environmental terms do not significantly improve the accuracy of the basic model. We can see however that the precision of the model containing TP is greater, in that the bias between rural and urban sites seen in the residuals is diminished (Figure 6).

Size spectra of dominant taxa

The overall abundance and size distribution in the urban and rural streams differ, and the magnitude of these differences varies among taxa. The Oligochaeta, Orthocladiinae and Hydropsychidae achieved greater densities per size class in the urban sites, whereas those of Ephemeroptera and Chironominae were higher in the rural sites.

The Oligochaeta demonstrated the largest difference in density per size class between the two regions. The urban size spectrum varied greatly, having approximately 10 individuals / m^2 in the smallest size classes (containing worms weighing less than 0.5 μg and measuring less than 1 mm) to around 600 individuals / m^2 in the mid range size classes containing organisms weighing approximately 4 μg and measuring 2 mm). The rural sites achieved a maximum density of approximately 20 individuals / m^2, and the range of size classes covered was shorter. The peak densities occured in the 2 to 4 μg range for both regions, which corresponds to organisms measuring between 1.4 to 2 mm. The differences in rural and urban size spectra were related to total phosphorus (Table 7). The inclusion of TP to the basic model including only the effect of body mass accounted for an additional 30% of the variance of density per size class.

The Ephemeroptera also diplayed very different size spectra for the urban and rural regions. The rural spectrum exhibited a unimodal shape, with maximum densities occuring in the 0.5 to 1.7 mm range. Densities in these size classes were also the most different from those in the urban sites. TP and current velocity improved the precision of the basic model by 18%.

The density of Orthocladiinae in intermediate and large size classes in the urban sites was almost tenfold greater than in the rural sites. The significant interaction of TP with body mass (Table 7) illustrated that this size related difference in density was correlated with TP. In comparison with the complete models containing TP for the other taxa, the model containing the effect of TP for Orthocladiinae was the best at predicting the observed spectra, obtaining an R^2 value of 0.83.

The density of Chironominae across the entire spectrum is higher in the rural sites. A unimodal shape is observed for both regions, with maximum densities occurring in the 1.2 to 1.6 mm range. There is a significant relationship between density and TP (Table 7). The predictive model containing the effect of TP ressembles the observed spectra ($R^2 = 0.7$) and explains 13% more of the variability in abundance per size class than the model including only body mass.

Hydroptilidae in urban sites had higher densities per size class than in rural sites, and the shape of the spectra differed between regions. The densities of individuals measuring less than 0.8 mm were similar for the two regions, and became more different in organisms above this size. The magnitude of the difference in densities varied for size classes containing organisms larger than 0.8 mm. The model seems to underestimate the urban densities in the size classes containing organisms larger than 0.8 mm, and also for the rural spectrum in size classes containing organisms under 2.4 mm in length. This poor fit is indicated by the relatively low R^2 value of 0.4. The observed difference in density between regions was related to TP and the interaction of TP and body mass, indicating a size dependent response to TP in the urban spectrum.

The size spectra of Hydropsychidae in general had a similar shape in rural and urban sites, and the magnitude of the differences seen in the observed spectra was not large, except in the largest size classes (individuals greater than 5.2 mm in length). In addition, the higher density was not in the same region for the entire spectrum. Larvae smaller than 0.6 mm had a higher density in the rural sites, whereas those individuals larger than 5.2 mm had a higher density in urban sites. The model which best fitted these spectra revealed TP, water temperature and sestonic chlorophyll to be significant predictors of density per size class. These terms and three interactions with body mass (Table 7) only increased the accuracy of the basic model by 10%. The urban size classes containing organisms greater than 5.2 mm in length were underestimated the most.

The size spectra of Tanypodinae were also quite similar for the two regions, despite the low densities making up the entire spectra. The differences in density between the rural and urban spectra ressemble that of the Hydropsychidae, however the high variability associated to the densities in most size classes make it difficult to conclude that there are genuine differences between regions. The complete model in Table 6 indicates that there is a correlation between density per size class and TP. The interaction term of TP and body mass indicates that there seems to be a size related difference as well. The complete model is 7% more accurate than the basic model which takes mass into account exclusively, however the fit in general is not as good as most of the earlier models of other taxa. This is especially the case for the urban sites.

Discussion

Taxonomic composition and environmental parameters

The differences in taxonomic composition of the invertebrate assemblages of urban and rural streams corroborate patterns generally observed. Dominance of one or two taxa within an invertebrate assemblage as seen in the urban sites is often reported for systems that are stressed (Clarke 1981; Cosser 1988; Resh and Jackson 1993; Lenat and Crawford 1994). Groups such as Orthocladiinae (Hershey et al. 1988), Oligochaeta (Lauritsen et al. 1985; Brinkhurst and Gelder 1991; Barton and Farmer 1997) and Physidae (Clarke 1981) contain species that are preadapted to the environmental conditions related to eutrophication, including lower oxygen concentrations, warmer temperatures and sometimes increased siltation (Dance and Hynes 1980; Lemly 1982; Barton and Metcalfe-Smith 1992; Lenat and Crawford 1994; Barton and Farmer 1997). Higher nutrient loadings stimulate the growth of algae and other primary producers such that food for herbivorous invertebrates is usually not limiting (Elwood et al. 1981; Hershey et al. 1988; Mundie et al. 1991; Perrin and Richardson 1997). Species that can withstand the adverse effects correlated with urbanization can therefore proliferate and often dominate these habitats. The rural sites contain a wider variety of dominant taxa presumably reflecting the lower physico-chemical stress in these streams (Stewart and Robertson 1992; Resh and Jackson 1993; Lenat and Crawford 1994; Rosenberg and Resh 1996). Meso-oligotrophic conditions support standing stocks of algae that are sufficient to support diverse benthic communities. Taxa such as Philopotamidae, Hydropsychidae and Simuliidae can be more efficient filter feeders with the lesser inorganic seston concentrations in the rural sites, and gill-breathing taxa such as Ephemeroptera, Plecoptera and many Trichoptera do not suffer the consequences of heavy siltation and low dissolved oxygen (Lemly 1982; Barton and Farmer 1997). Relative densities in rural sites are often not as high as those of the dominant taxa in urban sites maybe because of competitive interactions for space and food, that are more limited due to the more diverse fauna and lower abundance of periphyton.

Size structure and environmental parameters

The size distribution of individual taxa responded more to changes in TP than the size distribution of the entire assemblages. The density of organisms in the urban sites was up to three times greater than in rural sites when all taxa were included, whereas the differences of most dominant taxa were up to 32 times greater. The overall response observed for the size spectra including all taxa was a higher density of organisms in most size classes in urban sites. Responses of individual taxa were similar for Oligochaeta, Orthocladiinae, Hydroptilidae and in larger sized Hydropsychidae. The relative density per size class of individual taxa within the regions (Figure 5) illustrates that the largest differences in density between the spectra in Figure 4 correspond to Orthocladiinae (in the middle size classes) and Hydropsychidae (in the largest size classes). The dominance of these taxa within these respective size classes indicates that the difference between the rural and urban spectra of all taxa is really the response of Orthocladiinae and Hydropsychidae. These results suggest that what seems to be the effect of TP on the entire benthic assemblage is in reality the response of the most ubiquitous taxa, masking significant opposite responses that are occurring in taxa within the entire assemblage. Conclusions regarding the effect of eutrophication on the size spectra of entire benthic assemblages would therefore be incomplete, as we have demonstrated that responses and the magnitude of these responses of individual taxa within the assemblages differ significantly.

Responses of individual taxa

The magnitude and/or direction of the response illustrated by the dominant taxa varied according to size class for most groups. Kiffney and Clements (1996) reported size-dependent differences in response to heavy metals in their study of Ephemeroptera and Plecoptera survivorship in experimental streams. Bourassa and Morin (1995) related higher densities of invertebrates larger than 1 mm to higher concentrations of total phosphorus. The size-dependent responses that were encountered may be due to various factors, either methodological, ecological or both. To obtain a size distribution that is appropriate for generating predictive models, the density of organisms must be significant enough to represent a relatively large proportion of the entire assemblage. If the density is too low, the variability associated with rare taxa comes into play, and the interpretation of results becomes less conclusive. For this reason, the groups that were chosen to represent the dominant taxa of these assemblages were analyzed at a relatively coarse level of taxonomy. These groups may contain many species, which can cover select ranges of size classes within the entire spectrum of the group (ex. Hydroptilid species can vary from 2 to 3 mm to as big as 6 mm (Wiggins 1977)). Species-specific variations in body size could account for the differences in magnitude of responses for certain size classes within the spectrum of a given group, since many factors such as functional feeding, life cycle and behavioral strategies can differ among species (Rosenberg and Resh 1996), and therefore influence their tolerance to stress (Saether 1979; Lauritsen et al. 1985; Hilsenhoff 1988; Johnson et al. 1993; Townsend et al. 1997).

The urban spectrum of Ephemeroptera and the rural spectrum of Hydroptilidae demonstrated significant relationships to total phosphorus but contained a relatively low density of individuals per size class. These results should be regarded with caution, as these size spectra had low and variable densities per size class. The models should therefore be tested with spectra containing more individuals per size class overall to test the replicability of these results.

Potentially confounding factors

The level of taxonomy used in a study can significantly affect the outcome of analyses which classify taxa into discrete groups (Dance and Hynes 1980; Furse et al. 1984; Hilsenhoff 1988). That the spectra of individual taxa show a response, either positive or negative to total phosphorus but that the size structure of the entire assemblage is not as significantly affected indicates that taxonomic resolution influences the detection of responses. The relationships that we found support the hypothesis of Bourassa and Morin (1995) that these streams might be phosphorus limited. The inclusion of TP in most of the models suggests a relationship between the density of invertebrates and the productivity of their environment. Nevertheless, due to the correlations between TP, seston and periphyton, we are unable to conclude with certainty that the density of invertebrates is strictly dependent upon TP, as it could very well be an effect of any of these three variables or a combination thereof. These factors are direct (periphyton) and indirect (seston) measurements of potential food availability, which is a key factor influencing invertebrate distribution (Saether 1979; Elwood et al. 1981; Tokeshi 1986; Stewart and Robertson 1992). The effect of parameters that were not measured could also be influencing the responses, as many species respond differently to various types of pollutants. This inability to measure all possible effects is a common problem in natural field experimental designs (Norris and Georges 1993, Barton and Farmer 1997). Differences in land use in the surrounding areas of streams usually contribute highly to the physico-chemical status of the water. Toxic substances such as pesticides leached from agricultural land and heavy metals bound to suspended particles in urban streams especially after rainstorms can have devastating effects on invertebrate community structure (Stewart and Robertson 1988; Johnson et al 1993; Lenat and Crawford 1994).

The significant responses of the size spectra of the dominant taxa support the use of these groups as indicators of organic pollution. There is however an interesting discrepancy in the chironomid spectra responses. The negative response of the subfamily Chironominae is opposite of that which is usually seen by its Family in bioindicator studies. The actual spectra of Orthocladiinae illustrated a higher density of organisms in the larger size classes in the urban sites. This result is opposite of that obtained for Chironominae, which questions the validity of pooling chironomid subfamilies into one group when using this taxon as a bioindicator. When identifying the taxa within benthic invertebrate samples, most researchers pool chironomid species into their Family Chironomidae. Examples dealing with organic enrichment include Cosser (1988), Mundie et al. (1991), Barton and Metcalfe-Smith (1992), Stewart and Robertson (1992) and Lenat and Crawford (1994). This practise is related to the difficulty in species identification within this group, as well as the increasing use of rapid bioassessment practices to determine water quality in the shortest time possible (Resh and Jackson 1993). Taxonomic studies such as those of Lauritsen et al. (1985) and Tokeshi (1986) have shown, however, that the levels of tolerance of different species within a group can vary. Hilsenhoff (1988) has also pointed out that tolerance values in the Family Biotic Index can lead to erroneous interpretations of water quality due to the range of tolerance that is found within many arthropod families. The abundance of given taxa is often dependent upon complex species interactions such as competition for space and food (Cosser 1988; Johnson et al. 1993; Townsend et al. 1997), thereby causing difficulty in interpreting observations based on abundance indices. The high variability in chironomid responses at the species level is cautioned in recent rapid assessment literature (Resh and Jackson 1993).

Resilience of benthic community structure

The slight response of the spectra including all taxa despite significant responses from most of the dominant taxa support the hypotheses of Kerr (1974) and Borgmann (1982) that communities may be regulated by size-dependent processes. This would seem especially applicable to benthic communities as they have spatial constraints that limit the density of individuals that can survive in a given spatial unit. As the type of substrate has been hypothesized (Schwinghamer 1981) and shown (Bourassa and Morin 1995) to affect the size structure of benthic assemblages, we might expect that the mechanisms regulating the size structure of the total community will vary according to substrate type as well. For example, if a given reach consists of many types and sizes of substrate, which is in fact a characteristic trait of stream bottoms, we would assume that this allows for a greater diversity of organisms of various body sizes, as there would be a corresponding greater variety of ecological niches to be filled (Allan 1995). If such a non-uniform habitat supporting a diversified fauna was suddenly exposed to an increase in nutrients, we might expect that this assemblage would recover or adapt more quickly than, for example, one inhabiting a more uniform area, as the fauna here may be less diversified in relation to the habitat characteristics. This would be because most organisms of a given group will respond in the same manner to the stress, either by drifting or death. If this holds true, it would seem that the assemblages we studied are diversified to the point of quickly filling any gaps in the spectrum that would be created by sensitive taxa drifting or dying at the onset of stress. This would explain why the overall spectra of the rural and urban regions are not very different from one another despite the difference in taxonomic breakdown. Further studies comparing the spectra of the entire assemblage and of dominant taxa inhabiting various uniformities of substrate are needed to test this hypothesis regarding the effect of spatial variablilty on the resilience of benthic macroinvertebrate size spectra.

Conclusions

The taxonomic composition of the rural and urban sites varied in relation to the eutrophication gradient. The size distribution of these benthic assemblages was related to TP, however the magnitude of the difference in density per size class between regions was not as great as that of individual dominant taxa. Differences in response between regions when including all taxa were most influenced by the response of Orthocladiinae and Hydropsychidae. The negative response of Ephemeroptera and Chironominae were related to TP as well, however these responses did not seem to influence the overall effect observed for the entire assemblage. The importance of analyzing individual size distributions has been demonstrated accordingly.

Table 1. Location and surrounding characteristics of the 12 sampling sites.

Site	Latitude	Longitude	Landscape	Surficial Geology*	Canopy cover (%)
Ottawa-Hull					
Green	45.25'14"N	75.35'39"W	Urban, agricultural	Champlain Sea sediments - clay and silt	0
Des Trembles	45.25'53"N	75.45'50"W	Urban, agricultural	Glacial deposits - till Bedrock - limestone, dolomite, sandstone, shale	0
Leamy	45.28'07"N	75.44'52"W	Urban, wooded	Champlain Sea sediments - clay and silt	80
Sawmill	45.22'50"N	75.40'47"W	Urban, agricultural	Champlain Sea sediments - clay and silt	100
Outaouais					
Blackburn	45.38'40"N	75.48'59"W	Wooded	Bedrock - intrusive igneous and metamorphic rock	75
Corriveau	45.41'10"N	75.44'25"W	Wooded	Bedrock - intrusive igneous and metamorphic rock	65
Pelissier	45.39'45"N	75.44'20"W	Wooded	Champlain Sea sediments - sand Offshore marine and glaciomarine deposits - clay and silt Bedrock - intrusive igneous and metamorphic rock	45
Rainville	45.35'50"N	75.39'15"W	Wooded, agricultural	Bedrock - intrusive igneous and metamorphic rock	0
Gatineau Park					
Chelsea	45.30'14"N	75.48'44"W	Wooded	Champlain Sea sediments - sand Bedrock - intrusive igneous and metamorphic rock	75
La Peche Sud	45.36'07"N	76.06'18"W	Wooded	Glacio-fluvial ice-contact and ice frontal outwash deposits - gravel and sand Bedrock - intrusive and metamorphic rock	80
Renaud	45.36'07"N	76.03'29"W	Wooded	Bedrock - intrusive and metamorphic rock	0
Taylor	45.36'14"N	76.02'50"W	Wooded	Organic deposits - muck and peat Bedrock - intrusive and metamorphic rock	90

* adapted from Richard 1991, 1982, 1973

Table 2. Annual means (n=12) and standard errors (in parentheses) of environmental parameters measured at each site.

Site	Total Phosphorus (µg/L)	Seston (mg/L)	Sestonic Chlorophyll a (µg/L)	Periphyton (mg chl a/m^2)	Water Temperature (°Celsius)	Current Velocity (cm/second)
Ottawa-Hull						
Green	66.6	19.1	5.5	104.4	12.6	67.4
	(11.3)	(4.0)	(1.0)	(55.8)	(2.1)	(4.5)
Des Trembles	89.2	27.5	3.6	86.8	11.3	58.9
	(20.0)	(7.0)	(0.7)	(24.1)	(2.2)	(7.7)
Leamy	88.1	87.3	2.8	79.4	11.6	51.3
	(35.7)	(57.8)	(0.7)	(22.4)	(1.9)	(6.4)
Sawmill	56.2	22.0	4.6	37.9	11.7	46.1
	(5.3)	(2.9)	(1.1)	(20.5)	(1.7)	(6.1)
Outaouais						
Blackburn	9.6	0.9	1.1	0.6	13.1	69.3
	(0.9)	(0.2)	(0.2)	(0.1)	(2.6)	(7.0)
Corriveau	12.2	1.1	0.5	1.6	10.5	42.2
	(2.5)	(0.4)	(0.1)	(0.4)	(1.8)	(6.4)
Pelissier	15.1	2.1	1.7	48.4	10.3	60.4
	(1.9)	(0.4)	(0.5)	(42.8)	(2.2)	(8.9)
Rainville	15.0	1.3	2.3	4.6	14.3	73.8
	(3.0)	(0.2)	(0.7)	(1.3)	(2.7)	(6.9)
Gatineau Park						
Chelsea	17.0	2.2	2.1	2.0	11.6	51.6
	(2.0)	(0.2)	(0.6)	(0.6)	(2.2)	(4.4)
La Peche Sud	16.8	1.9	1.7	1.9	12.7	64.0
	(3.4)	(0.3)	(0.2)	(0.8)	(2.3)	(5.9)
Renaud	12.7	1.5	1.7	1.3	13.8	42.2
	(1.9)	(0.2)	(0.3)	(0.4)	(2.1)	(8.8)
Taylor	14.4	1.6	2.8	5.3	12.5	32.9
	(2.0)	(0.5)	(0.5)	(1.3)	(2.2)	(7.2)

Table 3. Pearson's correlation matrix for the annual average values of environmental variables (n=12). Coefficients indicated in bold lettering are highly correlated. Probabilities associated to significant correlations are indicated in parentheses.

	WT	log TP	log CHL	log SEST	log PERI	CV
WATER TEMPERATURE (WT)	1					
log TOTAL PHOSPHORUS (logTP)	-0.25	1				
log CHLOROPHYLL (logCHL)	0.43	0.51	1			
log SESTON (logSEST)	-0.28	**0.98** (< 0.001)	0.45	1		
log PERIPHYTON (logPERI)	-0.40	**0.86** (0.006)	0.54	**0.84** (0.011)	1	
CURRENT VELOCITY (CV)	0.31	0.06	0.33	-0.01	0.09	1

Table 4. R values (and probabilities) associated with regressions relating principal component factors to the environmental parameters measured. Variables were analyzed separately due to strong correlations between total phosphorus, seston and periphyton. Factor 1' is from the pca using all environmental parameters.

	Total Phosphorus	Chlorophyll a	Seston	Periphyton	Water Temperature	Depth	Current Velocity	Factor 1'
Factor 1	-0.78	-0.27	-0.75	-0.61	0.11	-0.17	0.23	-0.7
	(0.003)	(0.4)	(0.004)	(0.04)	(0.73)	(0.60)	(0.48)	0.01
Factor 2	0.47	0.02	0.47	0.41	-0.28	-0.14	0.49	0.41
	(0.12)	(0.95)	(0.12)	(0.18)	(0.38)	(0.67)	(0.10)	(0.19)

Table 5. R values (and probabilities) associated with regressions relating various individual taxa to the three significant variables from Table 4.

Taxa	Total Phosphorus	Seston	Periphyton
Orthocladiinae	0.77 (0.003)	0.82 (0.001)	0.66 (0.019)
Chironominae	-0.73 (0.006)	-0.72 (0.008)	-0.57 (0.05)
Oligochaeta	0.72 (0.008)	0.73 (0.007)	0.77 (0.003)
Ephemeroptera	-0.68 (0.014)	-0.68 (0.015)	-0.46 (0.13)
Physidae	0.85 (0.001)	0.81 (0.001)	0.87 (< 0.001)
Hydropsychidae	0.02 (0.96)	0.11 (0.72)	0.09 (0.77)
Hydroptilidae	0.47 (0.12)	0.47 (0.13)	0.34 (0.27)
Glossomatidae	-0.88 (< 0.001)	-0.92 (< 0.001)	-0.87 (< 0.001)
Philopotamidae	-0.61 (0.003)	-0.77 (0.003)	0.56 (0.056)
Limnephilidae	-0.65 (0.02)	-0.61 (0.03)	-0.6 (0.04)

Table 6. Predictive models for the mean annual size spectrum of the entire assemblage. The dependent variable is the $\log_{10}$ of (mean density per size class + 1). When the residual mean squares of models 2 and 3 are compared to the basic model using the F-statistic, we see that the inclusion of environmental parameters into the basic model does not significantly improve the precision. Legend : M-$\log_{10}$ (dry mass) (µg); TP-$\log_{10}$ (total phosphorus) (µg / L); CHL-$\log_{10}$ (sestonic chlorophyll *a*) (µg / L); TEMP-water temperature (°C).

Model (n=246)	Effect	Coefficient	Standard Error	p	R^2 model	RMS model	df	p (F-statistic)
BASIC	CONSTANT	2.695	0.041	< 0.001	0.86	0.14	242	
	M	1.22	0.044	< 0.001				
	M*M	-0.614	0.028	< 0.001				
	M*M*M	0.058	0.004	< 0.001				
2	CONSTANT	2.692	0.039	< 0.001	0.88	0.13	240	0.20
	M	0.773	0.122	< 0.001				
	M*M	-0.544	0.037	< 0.001				
	M*M*M	0.059	0.004	< 0.001				
	M*TP	0.333	0.086	< 0.001				
	M*M*TP	-0.056	0.021	0.01				
3	CONSTANT	3.266	0.251	< 0.001	0.89	0.12	238	0.05
	M	0.939	0.121	< 0.001				
	M*M	-0.562	0.036	< 0.001				
	M*M*M	0.059	0.004	< 0.001				
	M*TP	0.21	0.086	0.015				
	M*M*TP	-0.043	0.021	0.038				
	TEMP	-0.062	0.022	0.005				
	CHL	0.481	0.092	< 0.001				

Table 7. Predictive models estimating the density per size class of the seven dominant taxa. The effect of adding environmental variables into the basic model was tested by comparing the residual mean squares for the complete and basic models (F-statistic, $\alpha = 0.05$). Legend : M-$\log_{10}$ (dry mass) (μg); TP-$\log_{10}$ (total phosphorus) (μg / L); CHL-$\log_{10}$ (sestonic chlorophyll *a*) (μg / L); TEMP-water temperature (°C); CURRENT-current velocity (cm / s).

Taxa	Model	Effect	Coefficient	Standard Error	p	R² (model)	RMS (model)	df	p value (F-statistic)
Tanypodinae	BASIC	CONSTANT	0.626	0.118	<0.001	0.494	0.213	128	
		M	2.495	0.358	<0.001				
		M*M	-1.621	0.285	<0.001				
		M*M*M	0.258	0.062	<0.001				
	COMPLETE	CONSTANT	1.834	0.302	<0.001	0.565	0.186	126	0.223
		M	1.808	0.37	<0.001				
		M*M	-1.621	0.266	<0.001				
		M*M*M	0.258	0.058	<0.001				
		TP	-0.872	0.202	<0.001				
		M*TP	0.496	0.114	<0.001				
Orthocladiinae	BASIC	CONSTANT	2.043	0.072	<0.001	0.785	0.351	200	
		M	1.331	0.053	<0.001				
		M*M	-0.367	0.049	<0.001				
		M*M*M	-0.047	0.014	<0.001				
	COMPLETE	CONSTANT	2.043	0.065	<0.001	0.825	0.288	199	0.081
		M	0.807	0.092	<0.001				
		M*M	-0.367	0.044	<0.001				
		M*M*M	-0.047	0.012	<0.001				
		M*TP	0.378	0.056	<0.001				
Oligochaeta	BASIC 1	CONSTANT	0.838	0.072	<0.001	0.172	0.626	165	
		M	0.256	0.096	0.008				
		M*M*M	-0.094	0.019	<0.001				
	BASIC 2	CONSTANT	1.384	0.093	<0.001	0.401	0.456	164	
		M	0.2	0.082	0.016				
		M*M	-0.752	0.095	<0.001				
		M*M*M	0.18	0.038	<0.001				
	COMPLETE	CONSTANT	-0.943	0.181	<0.001	0.696	0.234	162	with BASIC 1
		M	-0.855	0.164	<0.001				0
		M*M*M	0.18	0.024	<0.001				
		TP	1.68	0.132	<0.001				with BASIC 2
		M*TP	0.761	0.109	<0.001				1E-05
		M*M*TP	-0.543	0.042	<0.001				
Hydroptilidae	BASIC	CONSTANT	0.833	0.069	<0.001	0.236	0.311	176	
		M	0.306	0.125	0.016				
		M*M	-0.351	0.1	<0.001				
		M*M*M	0.056	0.02	0.005				
	COMPLETE	CONSTANT	-0.33	0.234	<0.001	0.426	0.237	174	0.035
		M	-0.417	0.175	0.019				
		M*M*M	0.049	0.012	<0.001				
		TP	0.834	0.162	0.002				
		M*TP	0.492	0.16	<0.001				
		M*M*TP	-0.226	0.044	<0.001				
Ephemeroptera	BASIC	CONSTANT	1.35	0.06	<0.001	0.476	0.441	225	
		M	0.65	0.055	<0.001				
		M*M	-0.24	0.017	<0.001				
	COMPLETE	CONSTANT	1.856	0.22	<0.001	0.655	0.293	223	0.001
		M	0.65	0.045	<0.001				
		M*M	-0.239	0.014	<0.001				
		TP	-0.985	0.103	<0.001				
		CURRENT	0.477	0.091	<0.001				
Chironominae	BASIC	CONSTANT	1.183	0.076	<0.001	0.561	0.452	165	
		M	1.329	0.098	<0.001				
		M*M	-0.507	0.035	<0.001				
	COMPLETE	CONSTANT	2.651	0.184	<0.001	0.695	0.316	164	0.01
		M	1.329	0.082	<0.001				
		M*M	-0.507	0.029	<0.001				
		TP	-1.059	0.125	<0.001				
Hydropsychidae	BASIC	CONSTANT	-0.512	0.211	<0.001	0.448	0.321	188	
		M	2.662	0.346	<0.001				
		M*M	-0.876	0.155	<0.001				
		M*M*M	0.078	0.02	<0.001				
	COMPLETE	CONSTANT	-2.538	0.877	<0.001	0.55	0.269	183	0.115
		M	3.577	0.419	<0.001				
		M*M	-0.925	0.144	<0.001				
		M*M*M	0.078	0.018	<0.001				
		TP	-0.608	0.175	<0.001				
		TEMP	0.236	0.064	<0.001				
		M*CHL	0.213	0.083	0.011				
		M*TEMP	-0.081	0.023	<0.001				
		M*M*TP	0.036	0.018	0.043				

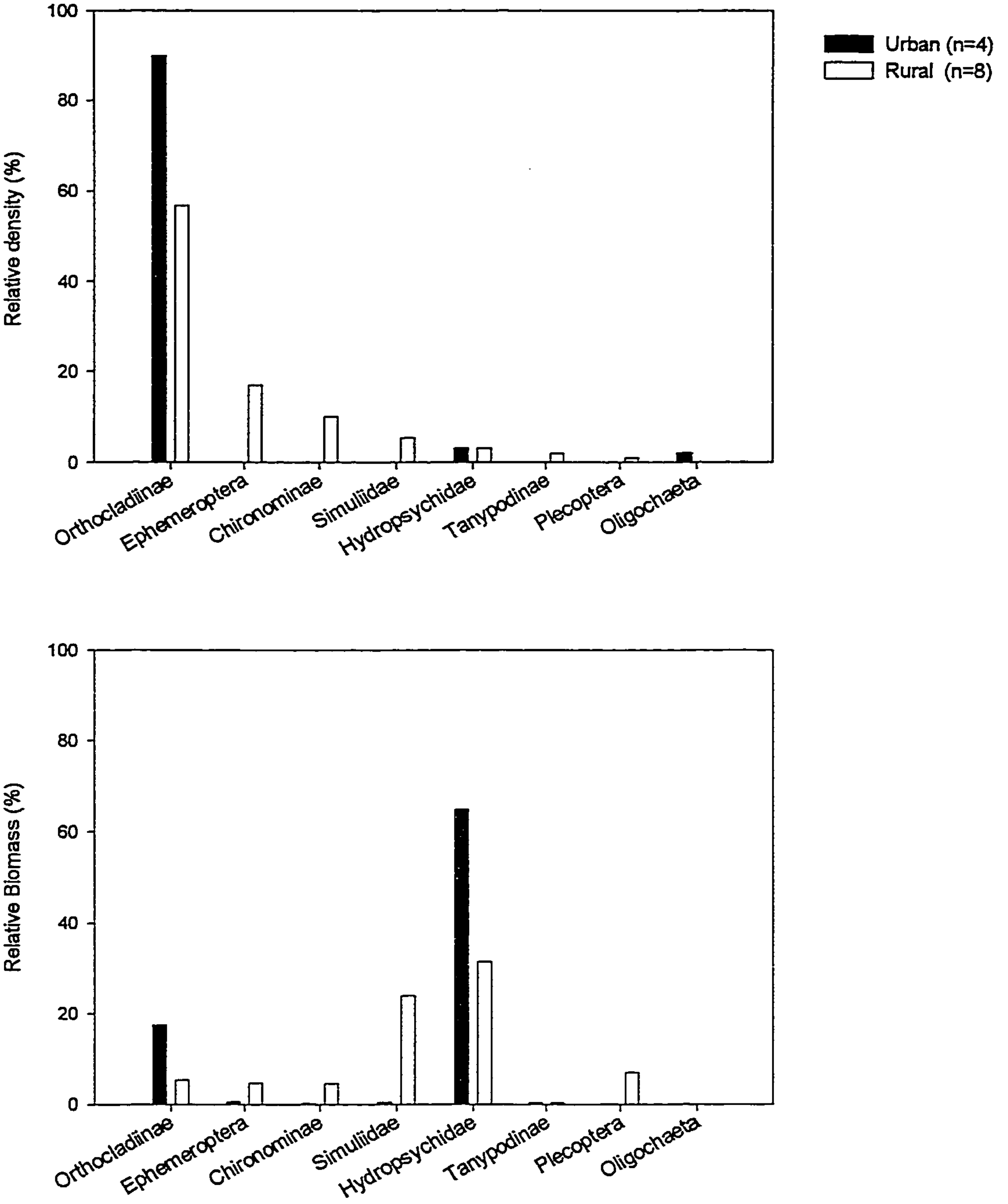


Figure 1. Relative density and biomass of dominant taxa representing 95% of the total in the urban and rural sites. Values are based on the mean densities per region. Note that the Orthocladiinae are dominant in density, but the Hydropsychidae represent the highest proportion of biomass in both rural and urban sites.

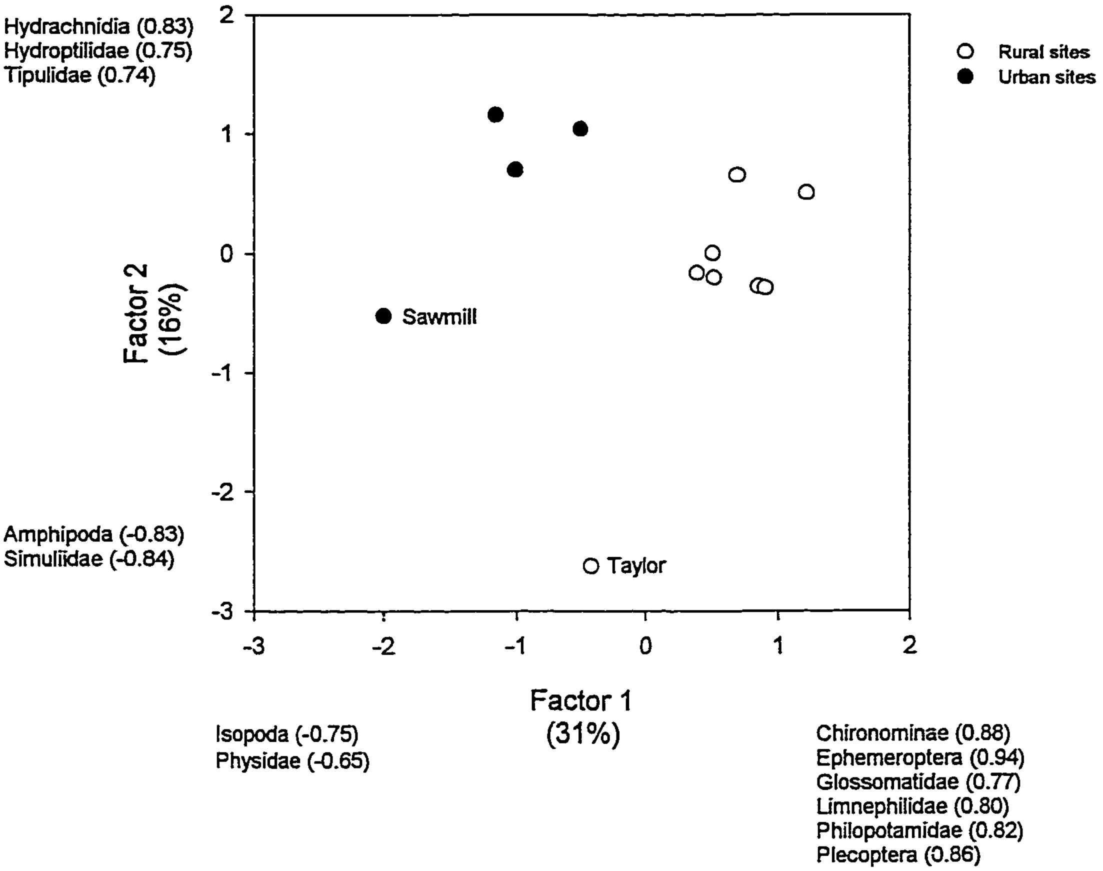


Figure 2. Separation of rural and urban sites onto the first two axes of the principal component analysis based on all 35 taxa. These two axes alone explain 47% of the total variation. Taxa indicated along the axes obtained the highest loadings (in parentheses).

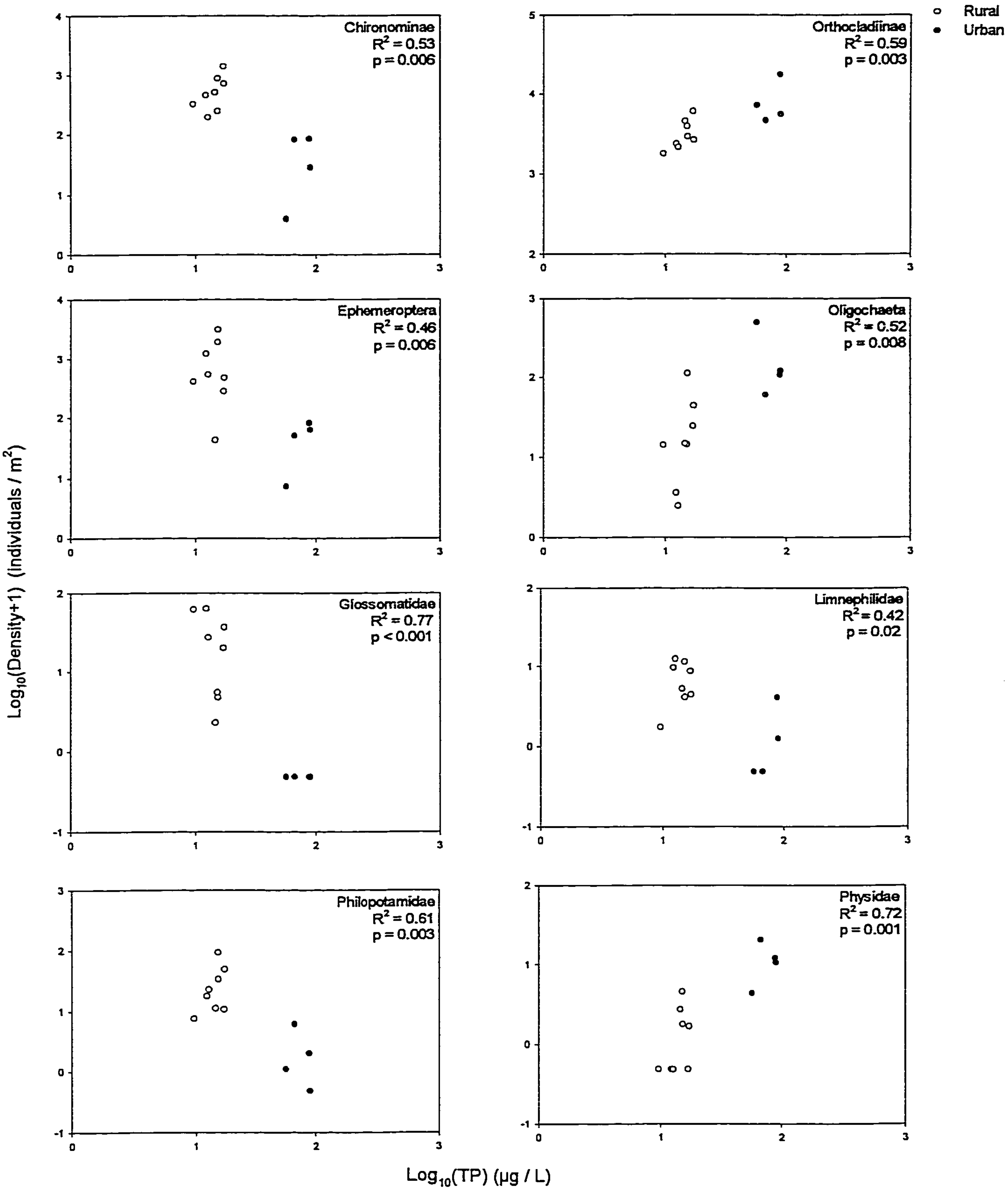


Figure 3. Correlations between total phosphorus and taxa that obtained high loadings on the principal component factor 1 axis or that were dominant overall.

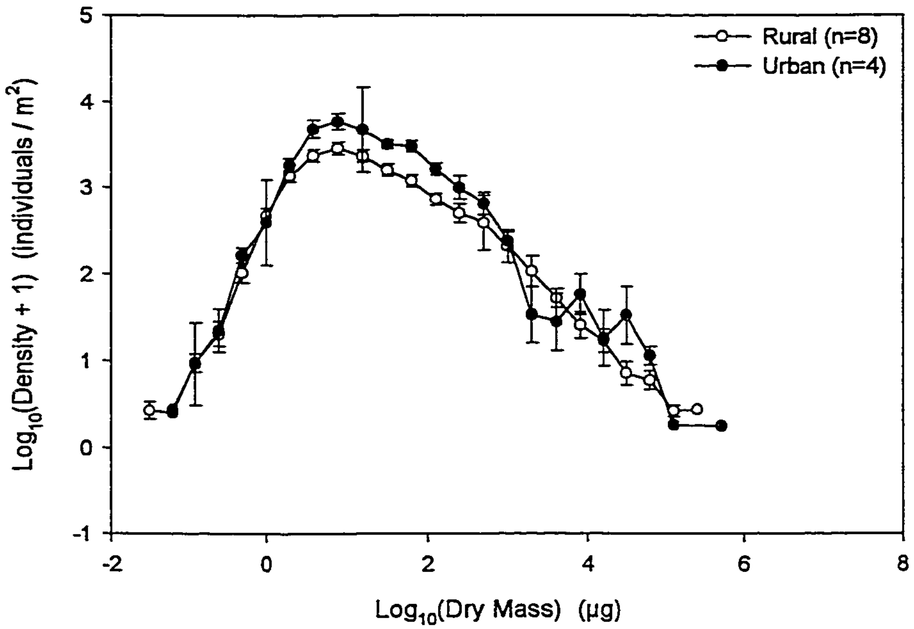


Figure 4. Annual average size spectra of the entire assemblage in rural and urban sites. Error bars indicate the standard error of the means.

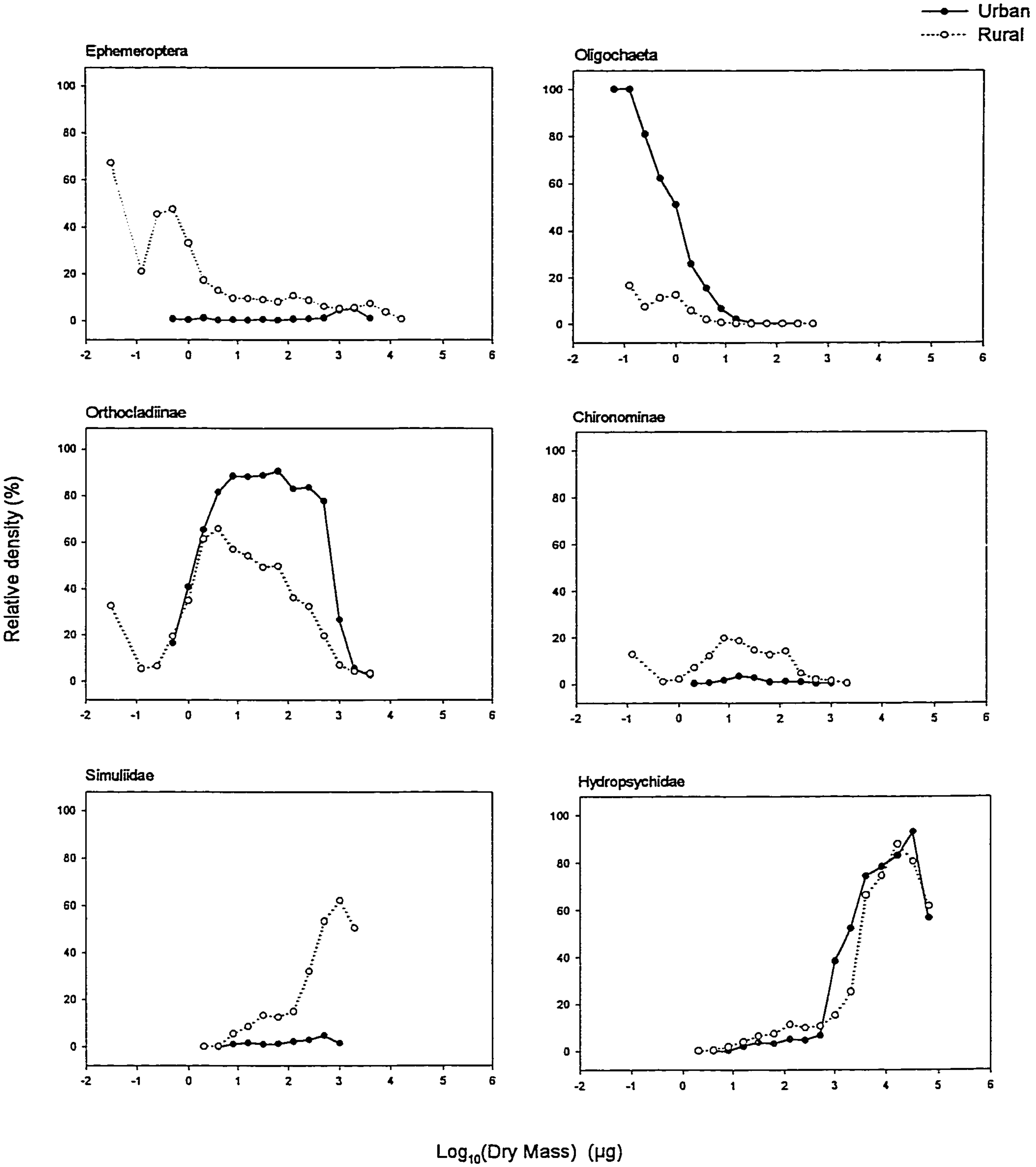
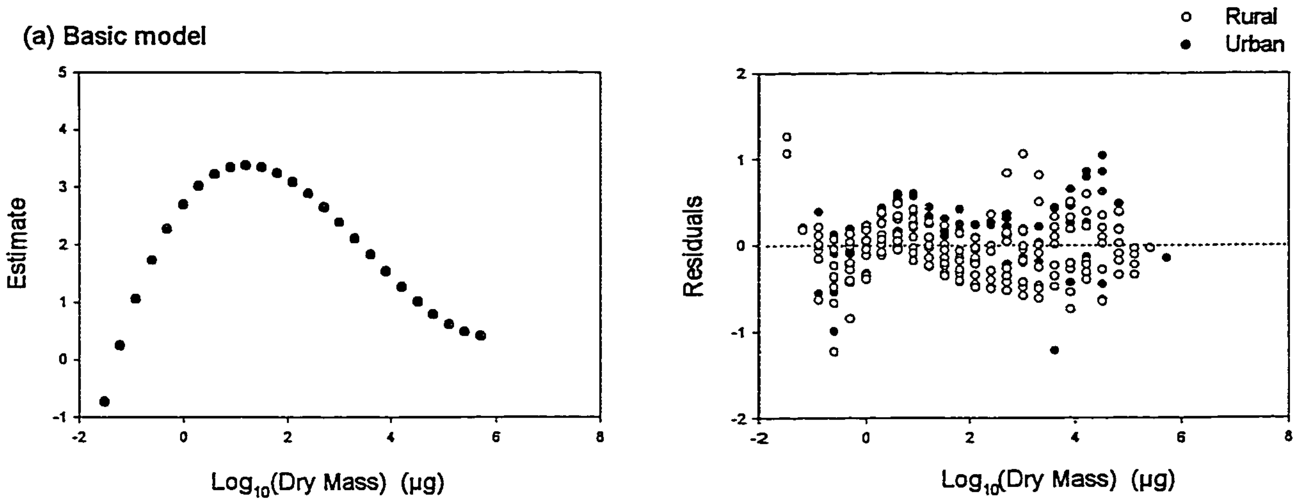


Figure 5. Relative densities expressed as a percentage of the total abundance per size class for dominant taxa. Plots of the relative biomass per size class for these taxa were virtually identical.

(a) Basic model



(b) Basic model + effect of TP

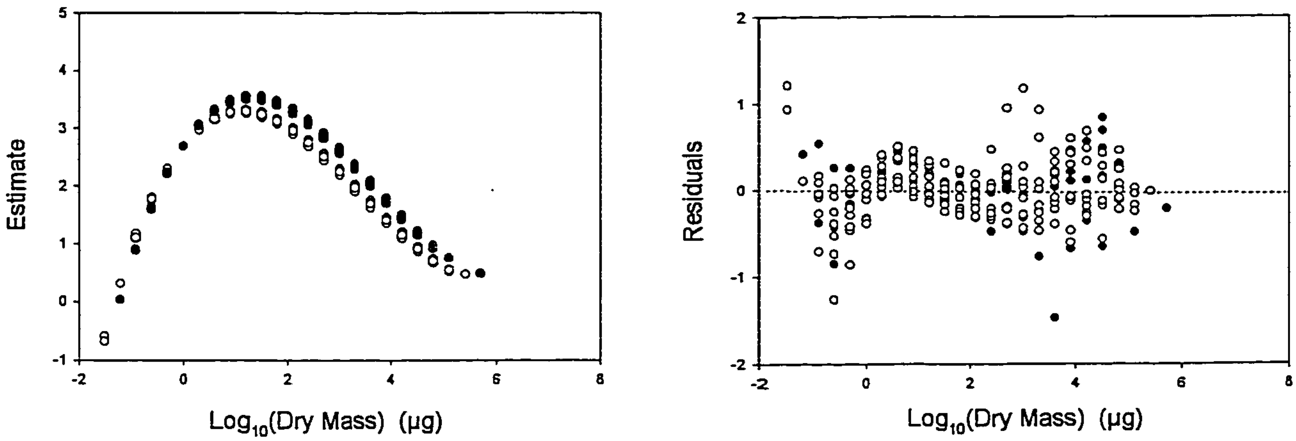


Figure 6. Predicted size spectra of all taxa using models listed in Table 5. The residuals are illustrated in the graphs on the right. Rural and urban plots overlap perfectly in (a). Each symbol represents the annual average density of all taxa in each size class for one site.

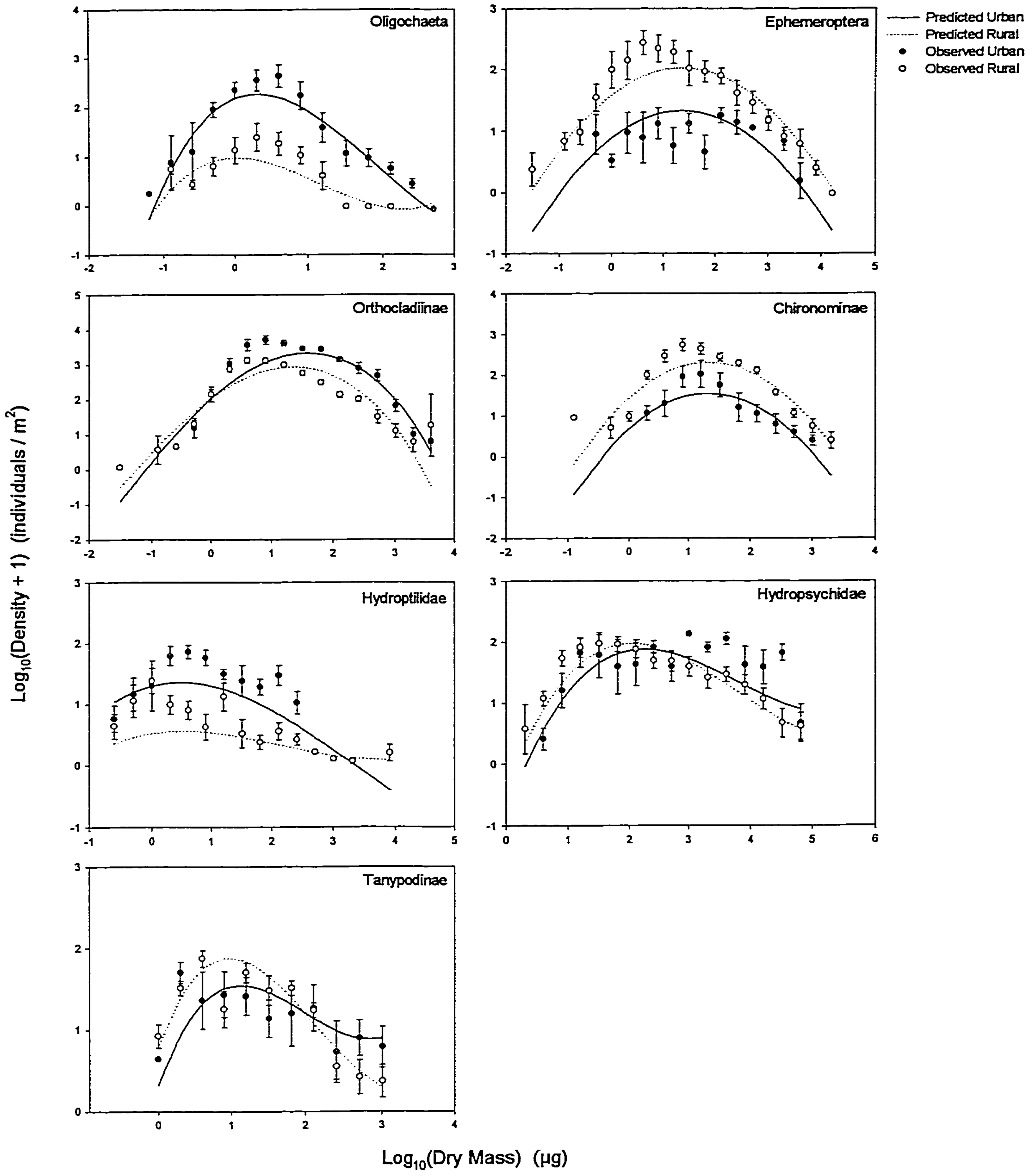


Figure 7. Observed (symbols) and predicted (fitted lines) size spectra of seven dominant taxa. Symbols represent the annual average density per size class (± 1 standard error) for each region. Predicted size spectra are from the most complete models (Table 6).

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Appendix 1. Listed are the intercept (*a*) and exponent (*b*) of models of the form $M = aL^b$, where M is the body mass (in μg dry mass) of an invertebrate and L is the body length (in mm).

Taxon	***a***	***b***	**Source**
Megaloptera	2.9001	2.75	Smock 1980
Plecoptera	2.2996	3.39	Smock 1980
Ephemeroptera	6.5979	2.88	Smock 1980
Anisoptera	2.2996	3.39	Smock 1980
Hydrachnidia	11.6576	2.4724	Meyer 1989
Oligochaeta	1	2	Ladle and Bird 1984, Jenderedjian 1994, Lindengaard et al 1994
Hydra	1	3	
Psephenidae	9.602	2.728	estimated from Adcock 1979
Elmidae(adult)	11.6576	2.4724	estimated from Meyer 1989
Elmidae(immature)	14.641	2.4594	Meyer 1989
Isopoda	9.602	2.728	Adcock 1979
Amphipoda	4.86	3	Marchant and Hynes 1981
Simuliidae	11.099	2.0742	Meyer 1989
Orthocladiinae	5.097	2.32	Smock 1980
Empididae	4.7453	2.7288	Meyer 1989
Chironominae	5.097	2.32	Smock 1980
Ceratopogonidae	0.085	3.795	Meyer 1989
Tipulidae	0.394	3.1059	Meyer 1989
Tanypodinae	3.8	2.41	Smock 1980
Planorbidae	58.2	2.8	Madsen and Flemming 1979
Ancylidae	35.7252	3.1403	Meyer 1989
Physidae	60.85	3	Gaten 1986
Hirudinea	1	2	
Rhyacophilidae	1.5934	3.1237	Meyer 1989
Polycentropodidae	1.9773	3.12	Smock 1980
Psychomyiidae	1.9773	3.12	Smock 1980
Hydropsychidae	4.3006	2.91	Smock 1980
Hydroptilidae	1.9773	3.12	Smock 1980
Glossomatidae	1.9773	3.12	Smock 1980
Helicopsychidae	1.9773	3.12	Smock 1980
Lepidostomatidae	1.9773	3.12	Smock 1980
Philopotamidae	1.9773	3.12	Smock 1980
Limnephilidae	1.9773	3.12	Smock 1980
Leptoceridae	1.9773	3.12	Smock 1980
Planaria	26.3998	1.8545	Meyer 1989

Appendix 2. Mean annual densities of the 35 taxa at each site.

	Blackburn	Chelsea	Corriveau	Des Trembles	Green	La PêcheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Hydrachnidia	5,73	29,96	4,56	5,10	16,30	11,56	27,13	66,64	3,88	7,99	2,03	0,00
Amphipoda	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,98
Anisoptera	0,90	0,00	0,83	0,00	0,00	2,47	0,00	4,58	0,00	1,21	0,00	0,00
Ceratopogonidae	0,00	0,69	0,00	1,25	0,00	0,00	3,05	1,60	0,00	0,75	0,00	2,69
Chironominae	322,07	717,30	458,07	28,10	82,01	1387,94	85,21	870,82	248,53	193,13	3,50	509,86
Elmidae (mature)	0,00	0,97	0,00	2,91	2,32	1,53	1,32	24,78	7,01	1,52	0,00	1,39
Elmidae (immatur	1,89	16,50	8,26	20,86	7,10	6,69	89,21	63,48	64,90	6,21	0,00	2,83
Empididae	15,61	48,66	2,18	3,95	16,30	27,37	43,80	54,96	14,73	25,03	30,84	28,10
Ephemeroptera	406,09	469,57	1209,03	63,00	49,80	280,14	81,56	3100,43	1895,75	536,36	6,77	42,29
Glossomatidae	61,13	35,86	62,24	0,00	0,00	19,37	0,00	4,25	4,95	26,57	0,00	1,82
Helicopsychidae	10,58	1,53	0,00	1,32	0,00	5,02	0,00	0,00	23,63	3,42	0,00	0,00
Hirudinea	0,00	0,00	0,00	0,00	1,67	0,83	0,00	0,98	0,00	23,53	0,00	1,96
Hydropsychidae	115,30	177,91	103,62	13,69	247,44	138,97	648,43	161,14	544,39	68,58	279,54	143,72
Hydroptilidae	24,09	41,55	8,68	69,64	70,45	41,85	111,30	19,13	6,85	7,72	2,54	4,03
Hydra	3,80	0,00	0,00	2,91	2,10	4,87	0,00	4,92	24,09	0,00	0,00	6,37
Isopoda	0,00	0,00	0,00	5,02	82,91	0,00	0,00	2,30	0,00	0,00	95,09	0,00
Lepidostomatidae	2,03	2,98	0,00	0,00	0,00	2,54	0,00	1,75	0,00	0,00	0,00	1,46
Leptoceridae	1,11	1,18	0,00	0,00	0,00	3,57	0,00	1,75	2,03	0,00	0,00	1,46
Limnephilidae	1,25	3,88	9,19	0,76	0,00	8,17	3,57	3,59	10,85	11,88	0,00	4,71
Ancylidae	0,00	22,51	0,00	0,48	58,75	0,00	12,47	2,54	0,00	0,00	14,73	40,96
Megaloptera	0,00	1,39	0,00	0,97	0,00	3,20	0,00	3,75	0,97	0,60	0,00	0,69
Oligochaeta	13,69	43,19	3,13	121,20	59,11	23,97	107,14	111,81	13,97	1,99	499,49	14,26
Orthocladiinae	1791,22	2645,75	2381,84	5566,39	4650,86	6083,33	17645,24	2915,73	3922,74	2170,68	7194,99	4588,33
Philopotamidae	7,10	48,34	17,30	0,00	5,57	10,23	1,53	32,98	91,14	22,18	0,62	10,67
Physidae	0,00	1,18	0,00	10,14	19,90	0,00	11,47	1,29	4,10	0,00	3,88	2,25
Planaria	2,54	9,45	0,62	3,42	10,49	0,97	4,79	0,00	0,76	1,52	0,69	0,69
Plecoptera	42,59	69,03	81,34	6,53	0,00	23,86	42,59	69,67	124,23	16,02	0,00	1,96
Polycentropodidae	1,46	3,50	2,76	0,00	2,54	2,91	3,13	2,86	4,56	7,72	0,00	0,00
Psephenidae	1,89	52,29	2,76	0,62	0,00	0,00	0,00	43,79	18,02	0,83	0,00	0,00
Psychomyiidae	1,67	0,00	0,00	0,00	1,25	0,00	0,00	0,00	0,00	0,90	0,00	0,00
Rhyacophilidae	14,93	15,71	10,58	0,00	1,32	1,32	48,18	37,42	7,01	6,73	0,00	0,00
Simuliidae	108,79	85,44	47,70	19,47	28,59	153,25	43,65	195,05	231,62	91,74	68,83	1608,26
Planorbidae	0,00	0,00	0,00	0,00	0,00	0,00	2,83	0,00	2,10	0,00	0,76	9,79
Tanypodinae	46,90	103,09	122,71	38,94	33,70	160,25	159,88	165,30	102,56	43,13	14,07	143,37
Tipulidae	4,56	48,82	14,73	18,74	69,84	35,31	13,03	118,11	21,73	3,26	0,00	0,00

Appendix 3. Mean annual densities per size class for each taxon at each site.

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Amphipoda	32												0.19
	2048												0.72
Ancylidae	2												1.16
	4												1.49
	8					1.09							1.72
	16		0.60			1.90						1.10	1.71
	32		0.77			1.60						0.70	1.45
	64					1.63		0.49					1.39
	128					1.51		0.06	0.88			0.69	1.69
	256		0.26			1.28		0.28				0.91	0.56
	512		1.28			1.53		0.78				0.51	0.83
	1024		1.17		-0.19	1.40		0.88				0.25	0.43
	2048		1.04			1.51		0.45				0.30	
	4096		0.97					0.67				0.76	
	8192		0.27			0.29						-0.05	
	16384											0.19	
Anisoptera	8192								0.33				
	16384			0.23									
	32768	0.25					0.24		0.77				
	65536						-0.05		0.14				
	131072										0.43		
	262144						0.25						
Ceratopogonidae	2										0.07		
	4								0.67				0.39
	8							0.23					0.69
	16				0.50			0.27					
	64		0.05										
	128							-0.08					
Chironominae	0.125						0.95						
	0.5		0.44								0.96		
	1	0.72	0.52	1.00			1.56		1.07	0.72	1.25		1.02
	2	1.85	2.29	1.73		1.25	2.46	0.88	2.06	1.65	2.16		1.77
	4	2.34	2.86	2.33	0.91	1.93	3.11	1.06	2.46	1.87	2.59		2.14
	8	2.39	3.20	2.50	1.56	2.41	3.40	1.90	2.80	2.19	2.88		2.54
	16	2.52	2.91	2.13	1.48	2.62	3.28	1.95	2.82	2.13	2.77		2.58
	32	2.44	2.32	2.12	1.35	2.32	2.91	1.57	2.47	2.05	2.77		2.41
	64	2.33	2.21	2.22	0.79	1.82	2.48	1.76	2.12	1.95	2.54	0.43	2.44
	128	2.02	2.49	2.28	1.00	1.59	2.30	1.06	1.76	1.79	2.13	0.55	2.13
	256	1.73	1.54	1.53	0.61	1.35	1.68	0.95	1.69	1.23	1.36	0.24	1.89
	512	1.31	0.93	0.85		0.75	0.92	0.45	1.11	1.11	0.60		1.67
	1024	1.02	0.47	0.17		0.26	1.24	0.51	0.62		0.30		1.33
	2048						0.60		0.19				

Appendix 3 (continued)

Taxon	Weight (µg)						Log (Density+1)						
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Elmidae	64						0,32		1,10				
(Mature)	128								1,72	0,45			
	256		0,30		0,50				0,76	0,79	0,10		
	512					0,71	-0,08	0,26		0,84	0,07		0,58
	1024				0,47								
Elmidae	4						1,30						
(Immature)	8				0,24		0,82	0,94					
	16								0,12	0,15			
	32	0,40	1,36		0,83			1,52	1,80	1,30			
	64		1,21	0,37	0,92	1,02	0,25	1,68	2,24	1,71			
	128		0,85	0,24	0,98	0,87		1,81	1,95	1,16			
	256			0,71		0,87	0,85	1,69	1,42	1,51			
	512			0,81		0,43		1,21	1,21	1,50			
	1024	0,12	0,47		1,31			1,18	0,12	1,67			
	2048		0,68		1,36			1,18	0,34	1,35			
	4096							0,77		0,11			
Empididae	1		0,43				1,06		0,93		0,29		1,45
	2		1,10			0,69			1,76		0,94	0,37	1,43
	4		1,43	0,35	0,23	1,11	1,60		1,98	1,32	1,20	1,12	1,35
	8	0,58	1,71	-0,13	0,70	1,61	1,48	1,27	1,54	1,27	1,20	1,04	1,69
	16	1,25	1,48				1,20	1,37	0,94		0,93	1,10	1,14
	32	1,07	1,31	0,02		0,71		0,62	0,65	0,88	1,19	1,28	
	64		0,91		0,63	0,04	0,43	1,24		0,98	0,34	0,80	
	128	0,40	0,56					1,06		-0,03		1,37	
	256					0,53		0,90					
	512											0,13	
Ephemeroptera	0,03125		0,38										
	0,125		0,98							0,69			
	0,25	0,37	0,82	1,09					0,58	1,31	1,72		
	0,5	1,12	1,74	1,68		0,64	1,33	1,27	1,83	2,17	2,20		0,27
	1	2,10	2,48	2,31	0,44	0,43	1,61	0,68	2,61	2,54	2,21		0,08
	2	2,16	2,51	2,57	1,50	1,51	1,75	0,72	2,84	2,70	2,47	0,15	0,11
	4	2,33	2,54	2,70	0,17	1,60	2,29	0,88	3,13	2,78	2,48	0,44	1,19
	8	2,38	2,47	2,54	1,55	1,39	2,07	1,10	3,14	2,77	2,34	0,04	1,04
	16	2,24	2,35	2,45	1,13	1,34	2,12	0,54	3,03	2,75	2,01	0,97	1,27
	32	2,10	2,13	2,30	1,59	0,87	2,04	1,05	2,84	2,47	1,97		0,19
	64	1,92	1,90	2,25	1,10	0,87	1,98	0,79	2,66	2,17	1,83	-0,13	0,98
	128	1,84	1,60	2,14	1,41	1,01	1,72	1,34	2,52	2,21	1,76		1,35
	256	1,41	1,54	1,79	1,30	0,76	1,82	1,35	2,29	2,07	1,51		0,43
	512	1,26	1,21	1,69	1,01	1,07	1,26	1,08	2,16	1,95	1,62		0,56
	1024	0,34	1,00	1,37	1,26	1,06	1,02	1,23	2,00	1,59	1,11		0,96
	2048	0,73	0,34	1,18	1,12	0,56	0,92	0,85	1,58	1,21	0,76		0,57
	4096			0,74	0,47		0,13	-0,10	1,31	1,27	0,52		
	8192			0,32			0,25		0,14	0,81			0,47
	16384	-0,04								0,02			

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Glossomatidae	2		0,57	0,45									
	4	1,10	1,33	1,19			1,43			0,55	0,75		0,86
	8	1,12	1,42	1,24			1,48		1,01	0,45	0,58		
	16	1,21	1,16	1,00						0,19	1,02		
	32	1,27	1,38	1,09			1,26				0,96		
	64	1,22	1,26	1,27							0,07		
	128	1,19	1,49	1,23					0,14	0,44	0,89		
	256	1,06	0,68	1,49							0,80		
	512	1,33	0,49	1,30			0,85			0,13	1,07		
	1024	0,98	0,37	0,83			0,61		0,22		0,77		
	2048	0,64	0,39	0,85			0,99				0,77		
	4096	0,20		0,56			0,45						
	8192	0,10											
Helicopsychidae	16	0,40								0,81			
	32									0,64			
	64		0,22							0,64			
	128	0,25								1,48	0,19		
	256	0,33	0,22							1,53	0,19		
	512	0,90					0,13			1,37			
	1024	0,78			0,55		0,76			0,52			
	2048	0,62					0,53			0,50	-0,12		
	4096	0,10					0,13				0,11		
	8192		0,22								0,11		
Hirudinea	4												0,19
	8										0,11		
	16										0,11		
	32								0,29		1,27		0,44
	64										1,79		
	128					0,29					1,82		
	256										1,79		
	512					0,04					1,21		
	1024						0,20						
Hydra	0,0625												0,19
	0,125								0,74	0,93			1,02
	0,25						0,82			1,40			
	0,5	0,83					0,94		0,52	1,22			
	1	0,40					0,85		0,74	1,36			0,79
	2	0,11			1,51	1,02	0,55			1,07			0,28
	4	0,40							0,46	0,95			
	8									-0,03			0,28
	16									0,18			

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Hydrachnidia	0,25								0,65				
	0,5						0,50		1,74		0,71		
	1	0,40	1,53	0,60			1,27		1,98	0,69	1,10		
	2	1,01	1,79	0,76		1,15	1,58		1,96	1,00	0,62		
	4		1,12	0,33		1,50		1,31	1,48	0,65		0,98	
	8		0,60		1,32	1,30		1,93	1,34				
	16				1,31	0,87		1,48	0,93				
Hydropsychidae	2									0,57			
	4	1,13	0,98			0,59	1,20			1,46	1,09	0,22	0,56
	8	2,00	2,00	1,16		1,50	1,77	1,47	1,15	1,87	1,71	0,63	2,16
	16	1,99	1,96	1,32	1,13	2,25	2,13	2,04	1,15	2,12	2,17	1,84	2,45
	32	1,76	2,26	1,68	0,72	2,35	2,12	2,15	1,15	2,29	2,01	1,91	2,48
	64	1,60	2,23	1,52	0,26	2,17	2,29	1,95	1,81	2,17	1,65	1,99	2,38
	128	1,64	2,05	1,26	0,61	2,22	2,10	1,92	1,67	2,32	1,53	1,76	2,43
	256	1,19	1,90	1,35		1,92	1,97	2,07	1,44	1,92	1,54	1,73	2,20
	512	1,37	1,99	1,60	0,91	1,89	1,68	1,97	1,58	2,11	0,80	1,59	2,32
	1024	1,29	1,70	1,51		2,13	1,66	2,17	1,41	2,01	0,80	2,08	2,35
	2048	1,16	1,61	0,79		2,06	1,24	1,91	1,41	2,03	0,90	1,77	2,16
	4096	1,25	1,34	1,42		2,15	1,03	2,17	1,58	1,85	1,22	1,85	2,01
	8192	1,09	0,95	1,13	0,76	2,10	0,73	1,98	1,72	1,82		1,64	1,62
	16384	0,88	0,80	1,40	1,02	2,08	0,62	2,03	1,61	1,79	0,57	1,19	0,80
	32768			0,99		1,84	0,13	2,03	0,87	1,25		1,59	0,11
	65536			0,26	0,00	0,35		1,25	0,59	1,01		1,10	
Hydroptilidae	0,25	0,37	0,27			0,97	1,12	0,56			0,81		
	0,5	1,24	1,14		1,12	1,92	1,54	0,96			0,29	0,65	
	1	1,18	1,26		1,06	1,93	2,00	1,98	1,09			0,25	
	2	0,47	1,47	0,77	1,78	2,06	1,48	1,52	1,25	0,62			0,88
	4	0,80	1,10		1,66	1,90	1,35	2,03	0,82	0,45			
	8	0,38	1,42		1,51	1,80	0,69	1,96	0,22				0,42
	16	0,68	1,43		1,51	1,35		1,62			1,25		
	32		1,08	0,29	1,42	0,92	0,69	1,78			0,04		
	64	-0,02	0,37	0,67	1,14	1,15	0,55	1,54		0,34			
	128	0,96	0,48		1,15	1,58	0,46	1,67	0,35				
	256	0,39	0,55	0,36	0,79	0,90	0,40	1,36	0,72	0,07			
	512	0,20		0,23									
	1024			0,07					0,07	0,19			
	2048								0,07				
	8192									0,20			

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Isopoda	8					0,59							
	16					1,55						1,27	
	32					1,77						1,32	
	64					1,70			1,07			1,35	
	128					1,68						1,44	
	256				0,50	1,72						1,54	
	512					1,64						1,34	
	1024				0,76	1,75						1,29	
	2048				-0,07	1,46						1,23	
	4096					1,19						1,40	
	8192				0,05	0,72						1,21	
	16384											1,19	
	32768											0,34	
Lepidostomatidae	4		0,46										
	16	0,07	0,82				0,54		0,46				
	32	0,23					0,50						
	64	0,07							0,16				
	128								0,16				0,62
Leptoceridae	4		0,46										
	8									0,16			
	16	0,07					0,54		0,46				
	32						0,50						
	64	0,07					0,32		0,16				
	128								0,16				0,62
	512									0,44			
Limnephilidae	2												0,28
	4		0,14										
	8			0,58				0,72		0,02			
	16			0,71			0,85			0,31			
	32		0,16	0,21			0,71		0,60	-0,07	0,27		
	64	0,19		0,37			0,39		0,28	0,65	-0,12		
	128	0,19	0,20	0,33				-0,24		0,42	0,52		0,78
	256				0,12		0,22		0,28		0,73		
	512			0,51			0,34			0,67	0,63		0,92
	1024						0,38	-0,21		0,76	0,81		
	2048			0,14			0,08			0,04	0,15		
	4096		0,05					0,13		0,66	0,70		
	8192		-0,07							0,02	0,08		

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Megaloptera	128						0,33						
	256		0,58				0,33		0,47	0,27			
	512						0,78						
	1024								0,35				0,08
	2048								0,56				
	16384				0,31								
	32768										-0,05		
Oligochaeta	0,0625											0,25	
	0,125	0,84				0,33			0,66			1,42	
	0,25		0,38	0,64	1,78		0,19	-0,09	0,66			1,62	0,32
	0,5	1,13	0,84		2,27	1,63	0,19	1,80	1,51	0,60		2,14	0,58
	1	0,67	1,40	0,14	2,72	1,91	0,85	2,49	2,28	0,93		2,29	1,68
	2	0,94	1,51		2,84	1,96	1,74	2,54	2,44	1,20	0,43	2,85	1,56
	4	0,56	1,68		2,98	2,07	1,01	2,48	2,14	1,07		3,05	1,20
	8	0,63	1,36		2,37	1,61		2,06	1,49	0,97	0,73	2,93	
	16			0,14	1,92	0,91	0,61	1,28	1,10			2,25	
	32				1,45			0,58		-0,01		1,19	
	64		-0,02		1,28			0,96				0,66	
	128		-0,02		0,89			0,64					
	256				0,53			0,36					
	512							-0,07					
Orthocladiinae	0,03125										0,07		
	0,125									0,57			
	0,25	0,65	0,60						0,74	1,82			
	0,5	1,08	1,42	1,28	1,93	0,88	1,39	1,27	0,79	2,61	1,41	0,68	1,29
	1	1,65	2,48	2,22	2,38	2,55	2,48	2,13	1,67	3,26	2,23	1,58	1,97
	2	2,70	2,78	2,82	2,97	3,37	3,25	3,15	2,71	3,39	2,74	2,67	2,80
	4	2,96	2,92	2,99	3,72	3,71	3,49	3,77	3,19	3,22	2,90	3,10	3,17
	8	2,88	3,10	2,93	3,92	3,66	3,42	3,87	3,11	3,05	2,94	3,38	3,37
	16	2,77	3,01	2,89	3,69	3,63	3,24	3,77	2,88	2,86	2,80	3,38	3,31
	32	2,68	2,74	2,64	3,42	3,40	2,97	3,60	2,71	2,64	2,43	3,41	3,06
	64	2,36	2,43	2,27	3,35	3,41	2,71	3,62	2,56	2,19	2,27	3,38	2,72
	128	2,02	1,91	2,10	3,12	3,20	2,35	3,25	2,37	2,13	1,72	2,97	2,48
	256	1,89	1,93	1,84	3,09	3,02	2,01	3,06	2,22	1,98	1,68	2,42	2,39
	512	1,51	1,45	1,31	2,93	2,65	0,86	2,92	2,04	1,32	0,72	2,24	2,11
	1024	1,04	1,33	0,48	1,82	1,94		2,16	0,84	0,56	0,70	1,36	1,95
	2048	0,66	1,62			1,16		1,35			0,30	0,59	
	4096		1,26			0,86		0,75					

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Philopotamidae	2								0,70		0,65		
	4		1,01	0,26		0,87			0,94	0,81	1,01		
	8		1,55	0,58		0,78	0,81		0,94	1,07	1,25		0,22
	16	0,58	1,12	0,88			0,87		1,40	1,21	1,75		1,14
	32		1,38	0,98		0,43	0,80	0,63	0,40	1,13	1,55		0,27
	64		1,28	0,83			1,11		1,14	1,23	1,64		0,80
	128		1,43	0,92			0,80		1,01	1,07	1,67		
	256		1,55	0,56			0,90		0,06	1,23	1,42		
	512	0,55	1,25	1,02			0,30			1,19	1,41		0,22
	1024	0,34	1,26	1,01			0,20		0,32	1,39	1,31		0,89
	2048	0,74	0,51	0,82		-0,01	0,60		0,41	1,00	1,47		
	4096	0,63	0,96	0,31			0,66			1,35	1,37		0,35
	8192		0,54	0,16						0,88	1,43		0,84
	16384		0,38									-0,04	
Physidae	32				0,42								
	64				0,42								
	128				1,07							0,37	
	256		0,16		0,42					0,65		0,33	
	512					-0,01		-0,05	0,49				0,38
	1024		0,16		0,31	0,69		0,55		0,35		-0,05	
	2048				0,32	1,13		0,60					0,42
	4096					1,12		0,97				0,51	
	8192				0,68	1,27		-0,08					
	16384					1,03		0,66		0,25			
	32768				0,42	0,55		0,51		0,48			
	65536				0,88	0,51							
	131072				-0,07								
	524288							-0,10					
Planaria	32	-0,14		0,00									
	64		0,46			0,60		0,94					
	128	0,10	0,74		0,79	0,61		0,59		0,13			
	256		1,29		0,80	0,51	0,30	0,61			-0,02		
	512	0,20	0,76			1,30		0,03			0,13		
	1024	0,20				1,07		0,03				0,08	0,08
Planorbidae	16									0,65			
	32												0,82
	64												0,56
	128												0,78
	256							0,26					0,67
	512									-0,05			0,87
	1024							0,07					0,92
	16384							-0,03					
	65536											0,11	

Appendix 3 (continued)

Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Plecoptera	0,25	0,13							0,58	0,22			
	0,5	0,72	0,58	0,76			0,24		1,21	1,13			
	1	1,03	1,02	1,60				1,26	1,43	1,68	0,65		
	2	1,14	1,53	1,77				1,64	1,61	1,47	0,76		
	4	1,19	1,20	1,25	0,15		0,24	1,99	1,35	1,45	1,08		0,58
	8	0,40	0,95	1,24	0,89		0,60	1,62	1,29	1,07	0,19		
	16	0,56	0,73	1,28	0,33		0,17	0,12	1,47	0,82	0,15		
	32	0,03	0,87	0,68	0,02		0,17	0,50	1,08	0,19	0,71		
	64	0,41	1,18	0,99					0,65				
	128	0,56	0,61	0,52			0,24	1,20	0,64	0,94	-0,12		
	256		0,47	1,33			0,40	0,24	0,80	1,15			
	512	0,90	0,50	0,67			0,90	0,29	0,86	0,99			
	1024	0,26	0,76	0,85			0,74	0,68	0,47	1,17			
	2048	0,10	0,97	0,45				0,20	0,76	1,07			
	4096	0,55	0,47					0,24		1,22	0,13		
	8192	0,53	0,30				0,22			0,51	0,44		
	16384	0,09	0,35	0,31			0,54			0,68	0,48		
	32768	0,13	0,16				0,94			-0,01	0,30		
	65536			0,10			0,66			0,61			
	131072	-0,07		0,33						0,15			
Polycentropodidae	4			0,04				0,63					
	8		0,52			0,62				0,75	0,88		
	16		0,19			0,62		0,63		0,45	0,61		
	32		0,66							0,45	0,40		
	64	0,07		0,37									
	128		0,52	0,30			0,55		0,69	0,45			
	256						0,30		0,47		0,01		
	512									0,07	0,46		
	1024	0,09				-0,01	-0,08	0,26		0,02	0,40		
	8192									0,13			
Psephenidae	4		0,66										
	8		1,19						0,12	0,15			
	16	-0,04	1,35							-0,07			
	32	-0,04	1,65	0,37					1,21	0,97			
	64		1,47						1,69	0,61			
	128		1,27						1,13	0,66			
	256	-0,07	1,06		-0,04				1,15	0,59			
	512	-0,07	0,94	0,81					0,99	-0,07	0,16		
	1024		1,01						0,99	0,66			
	2048		0,99							1,10			
	4096		0,58							0,50			
	8192		0,17										

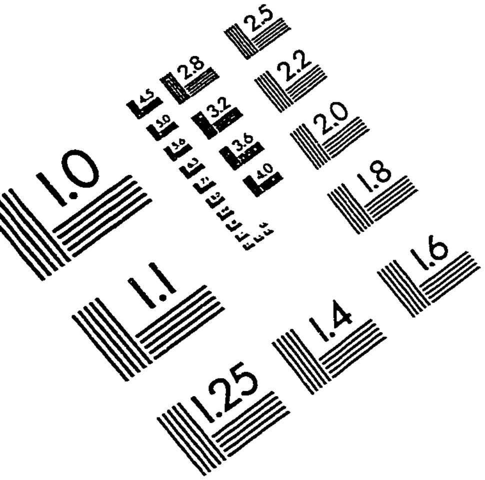
Appendix 3 (continued)

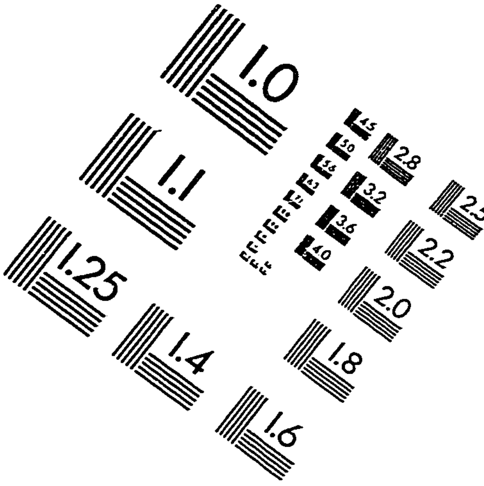
Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Psychomyiidae	8	0,50											
	16	0,50				0,49							
	32										0,19		
Rhyacophilidae	1							0,88					
	2							0,88					
	4							0,88					
	8		0,57					0,88					
	16							1,00	0,52				
	32	0,98	0,57	0,83				1,05	1,29	0,02	0,21		
	64	0,59	1,32	0,29			0,04	1,16	0,93	0,48			
	128	0,47	0,57	0,47				1,31	1,22	0,42	0,16		
	256	0,98	-0,00	0,16		0,56		1,04	0,83	0,27	0,21		
	512	0,07	-0,03	0,61				1,11	0,79	0,01			
	1024	0,37	0,70	0,46			-0,05	1,11		0,59			
	2048	0,50							0,35		-0,09		
	4096								0,22				
	8192			0,45					0,92				
	16384								0,52		0,10		
	32768	0,09							0,28		0,15		
	65536	0,25							0,47		0,59		
Simuliidae	2												0,17
	4	0,98		0,65			0,86		1,41		0,57	0,33	1,24
	8	1,54	1,79	1,57		1,60	1,65	1,65	2,28	1,82	1,81	2,14	3,12
	16	1,80	1,61	1,50	0,42	1,80	1,92	2,16	2,26	2,08	2,16	2,13	3,17
	32	1,64	1,78	1,34	0,76	1,35	1,96	1,80	2,15	2,05	2,10	1,78	3,26
	64	1,62	1,65	1,47	0,95	1,83	1,67	1,57	2,16	2,06	1,88	1,23	3,08
	128	1,41	1,79	1,04	0,77	1,98	2,20	0,97	2,34	2,08	1,53	0,04	2,80
	256	1,49	1,62	1,60	1,08	1,76	2,61	0,86	2,03	2,15	1,48	1,23	3,09
	512	1,36	1,28	1,31	0,63	1,77	2,65	0,95	2,02	2,25	1,46	1,41	3,41
	1024	0,91	1,04	0,14	0,44	0,37	2,07	0,59	1,65	1,95	1,15	0,63	3,38
	2048		0,35				1,33		1,08	2,29	-0,05		2,82
Tanypodinae	1	0,70	1,34	0,48			1,21	0,64			0,71		1,08
	2	1,23	1,28	1,57		1,83	1,89	1,57	1,35	1,54	1,36		1,83
	4	1,75	1,82	1,99	1,54	1,49	2,37	2,02	1,75	1,74	1,45	0,37	2,11
	8	1,53	1,84	2,15	1,50	1,31	2,32	2,13	2,12	1,86	1,43	0,79	2,10
	16	1,44	1,66	1,96	1,22	1,30	2,03	2,08	1,83	1,72	0,98	1,06	1,97
	32	0,93	1,24	1,96	0,81	1,16	1,90	1,80	1,57	1,51	0,69	0,80	2,07
	64	1,18	1,38	1,54	1,78	1,33	1,64	1,64	1,49	1,83	1,21	0,04	1,79
	128	0,84	0,91	1,36	1,93	1,24	1,18	1,37	1,55	1,30	1,38	0,56	1,37
	256	0,90	0,47	0,91	1,09	-0,03	0,64	1,12	1,18	1,28	-0,12		0,70
	512	-0,02	0,84		1,38	0,73		1,08	1,23	0,01	0,32	0,39	0,11
	1024	-0,02	0,38		1,42	0,74		0,78	0,90			0,21	0,21

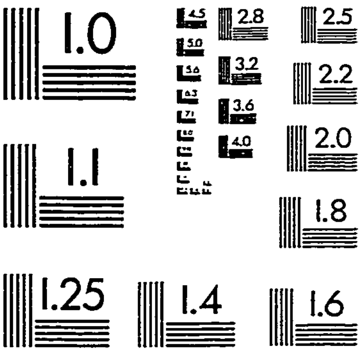
Appendix 3 (continued)

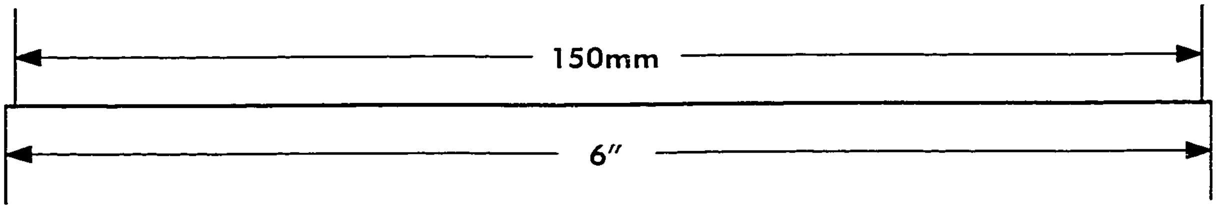
Taxon	Weight (µg)	Log (Density+1)											
		Blackburn	Chelsea	Corriveau	DesTrembles	GreenCreek	LaPecheSud	Leamy	Pelissier	Rainville	Renaud	Sawmill	Taylor
Tipulidae	0,125		0,60								0,21		
	0,25		1,18		1,00	0,69					0,21		
	0,5		0,86			1,30				0,21			
	1	0,55	1,33	1,12	0,47	1,30	1,39		1,29	0,65			
	2	0,40	1,53		1,68	1,81	1,00	0,04	1,38				
	4	0,37	1,24	0,91		1,43	1,11		1,59	0,44	0,40		
	8		1,34	0,85		1,22	0,99		1,82	1,03			
	16	0,07	0,76	0,77		1,58	1,19		1,85	0,65			
	32		1,31		0,93	1,33	1,20	0,59	1,84	0,48			
	64	-0,02	1,16	0,10		1,47	1,07	0,36	1,34	1,18			
	128		0,53		0,31	1,25	0,53	0,50	0,40	0,78			
	256		1,27	0,37	0,96	1,31	0,39	0,88	0,22	0,80	0,07		
	512				0,47	0,94	0,22	0,69	0,39	0,18			
	1024							-0,12					
	16384							-0,09					

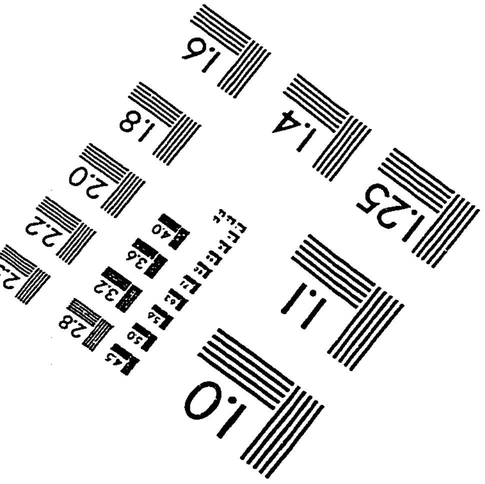
IMAGE EVALUATION
TEST TARGET (QA-3)

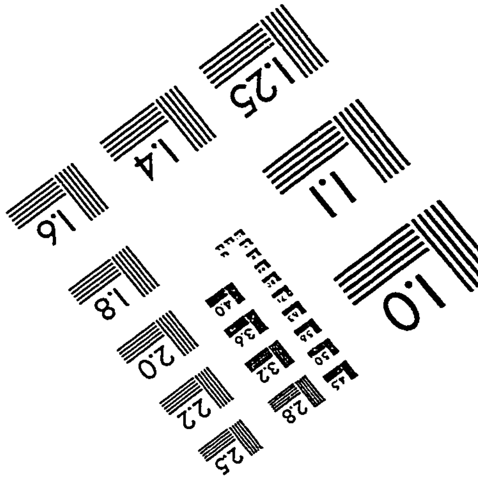












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