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Bioassessment of Urban Streams (Johnson Creek and Tryon Creek) Portland, Oregon

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Introduction

Environmental scientists face great challenges in studying the dynamics of urban ecosystems across temporal and spatial scales. Urbanization is a process of land transformation from agricultural/natural land to a human-dominated urban system. Nearly half of the world's population currently resides in urban areas and urbanization is still increasing at an alarming rate (UN 1997). Urbanization has become one of the major environmental stressors on ecosystems (Grimm et al. 2000). For example, a 20- year study of ecosystem processes along an urban-to-rural gradient suggested that urbanization may attribute to alteration of forest ecosystem processes, such as decomposition and nutrient cycling in urban areas (McDonnell et al. 1997). Increases in urban land use to 10-20% in watersheds may result in poor fish assemblages and overall biotic integrity in Wisconsin streams (Wang et al. 1997).

Characterization of environmental changes along an urban-to-rural gradient may be an effective approach to study such complex urban ecosystems (McDonnell and Pickett 1990). The metropolitan area of Portland, Oregon is an ideal place for studying the effects of urbanization on ecosystems along the urban-to-rural gradient. Unlike other metropolitan cities that developed across the landscape without control, an Urban Growth Boundary (UGB) was enacted in 1972 to contain the 20-year's urban growth within the boundary (Metro 1997). This unique boundary allows the comparison of highly urbanized watersheds to rural watersheds outside the boundary having similar characteristics.

This study was funded by the City of Portland Bureau of Environmental Services. The 1st main objective of the study was to assess the spatial variation of biota such as macroinvertebrates and diatoms in two urban streams (Johnson Creek and Tryon creek) and two adjacent rural streams (Clear Creek and Deep Creek). It was expected that as integrators of overall environmental conditions in watersheds and streams, biotic assemblages in urban and rural streams with contrasting land-use types and intensities would be different (Stanley and James 1997, Carpenter and Waite 2000). The 2nd main objective was to classify stream sites based on biota and thus individual urban sites could be compared with rural sites based on similarity of the biotic composition. In addition, we also classified stream sites in Johnson Creek alone so that urban stream sites could be ranked based on the biota. The 3rd main objective was to assess temporal variation of biota between the urban and rural streams. It was expected that temporal variation of environmental conditions, such as precipitation during the wet season, might change the relationship between species assemblages and surrounding spatial conditions. Moore (1978) found seasonal population shifts for epilithic algae in rivers and that densities were limited by high water velocity. Also, epilithic algae have been correlated with fluctuations in water chemistry, flow, and temperature streams of British Columbia (Wehr 1981)

Methods

Study Area

Stream sites were sampled from Clear Creek, Deep Creek, Tryon Creek, and Johnson Creek, located in the plains and foothills of the Willamette Valley Ecoregion (Figure 1, Table 1). The plain, approximately 170 km long and 70 km wide, is a trough between the Coastal Range in the west and the Cascades in the east with modest relief (Uhrich and Wentz 1999). Land use and cover in the ecoregion are comprised mostly of agriculture with some forest and urban area (Clarke et al. 1991). The proximity of the Willamette Valley to the Pacific Ocean and the prevailing weather patterns produce a temperature regime characterized by cool wet winters, and warm dry summers. Annual precipitation ranged from 102-127 cm from 1961-1990 (Uhrich and Wentz 1999). Most of the precipitation *(~75%)* occurs from October through March with *<5%* occurring during July and August (Uhrich and Wentz 1999). Streamflow in Willamette Valley streams is tightly coupled with precipitation. Bonn et al. (1995) estimated that low flow in the Willamette River basin streams during August and Sept. only accounts for <2% of total annual streamflow. Average monthly air temperatures range from *3-5* "C in January and 17-20 "C in August (Uhrich and Wentz 1999).

Watershed land use in Johnson Creek and Tryon Creek ("urban") is different from the other two "rural" watersheds. Johnson Creek is mostly urban (66%) at the west end of the watershed characterized by residential, industrial, and commercial land use (Metro 1997). Impervious surface area (ISA) was approximately *65%* (Meross 2000). The eastern portion of the watershed is primarily used for agricultural activities (13%), such as Christmas tree farming, crop cultivation, grazing and for rural living (21%) (Woodward-Clyde Consultants *1995,* Metro 1999). Land use in Tryon Creek is primarily dominated by forested park area and open space. However, most of the headwater areas are occupied by urban residential with some commercial land use (Metro 2000). The Clear Creek watershed has mixed land use associated with forest (34%), agriculture *(5* 0%), and rural living (15%). Land use within Deep Creek is similar to Clear Creek having uses such as forest (24%), agriculture (39%), and rural living (3 1%) (Metro 1999). Percent of ISA was 11% for Clear Creek and 20% for Deep Creek (Metro 1997). Johnson Creek was thought to have supported healthy salmonid populations in the past (Woodward-Clyde Consultants *1995).* The two rural streams both currently support various salmonid species (Oregon Department of Fish and Wildlife 1996, Metro 1997). These watersheds have similar physical characteristics, except Tryon Creek. Areas in the Clear Creek, Deep Creek, and Johnson Creek watersheds are similar in size (108 1cm2, 123 1cm2, and 134 km2 respectively) and have similar stream gradient. Tryon Creek's physical characteristics are somewhat different from the three other basins. The gradient of the basin is probably the most noticeable difference among the other basins. Tryon Creek contained steep slopes in the park area, as high as up to 40% hillslope. Tryon Creek also has the smallest watershed area. More detailed watershed descriptions are summarized by Walker (2001) and Hoy (2001). The rural watersheds were chosen due to their proximity to Johnson Creek and were outside the Urban Growth Boundary.

Field Sampling

A total of 65 sites were sampled for physical, chemical, and biological parameters during late August through early September of 1999. Of *65* sites, 30 were in Johnson Creek, 15 in Tryon Creek, 12 in Clear Creek, and 8 in Deep Creek. Of 30 sites in Johnson Creek, 25 were on the main stem of Johnson Creek. Other sites were in a few major tributaries to Johnson Creek such as Crystal Spring and Kelly Creek. In addition, one downstream site in Johnson Creek (urban) and in Clear Creek (rural) was selected for sampling throughout the year. These sites were sampled monthly for diatoms, macroinvertebrate and water chemistry. Stream discharge was measured continuously in the Johnson Creek site at a US Geological Survey (USGS) gauging station located just above the urban site.

In 2000, the eight sites in Deep Creek were not sampled because the 1st year data revealed that this stream may not serve well as a 'good' rural reference site. A few sites in both Johnson Creek and Tryon Creek were not sampled due to dried channels.

Study Unit

The sampling unit was riffle habitats ranging from 5 m to 20 m. Five cross-section transects were set up in each study riffle by dividing the riffle into four equal length intervals. Three transects were utilized when the length of available riffle habitat was limited (e.g., small tributaries). Stream physical habitat characterization included channel morphology, substrate, riparian area condition, and discharge. Thalweg depth and width were measured at each transect in the riffle habitat. Channel gradient was measured for the entire sampling area using a Suunto clinometer. Stream discharge was measured using a flow meter. The amount of fine sediment (<2 mm) at each site was assessed by randomly placing a grid on the streambed at 20 locations and counting intersections with fine sediments (Torquemada and Platts 1989). A qualitative assessment of riparian and stream conditions were made using the EPA's Rapid Bioassessment Protocol on the habitat assessment (RBP)(Barbour et al. 1999).

Water Quality

Water samples were taken in the middle of the stream for nutrient analyses. Stream water was sampled using acid-washed 250 mL DHPE Nalgene® sample bottles. Sample bottles were rinsed with stream water three times prior to actual sampling. Two water samples were taken, one filtered on-site, another unfiltered, then both stored on ice during sampling. After sampling, water samples were filtered through 47 mm Millipore® type HA filters *(0.45* pm pore size) using a Nalgene® hand pump filtration unit, then processed for nutrient analysis. Conductivity normalized for temperature, dissolved oxygen (DO), and stream temperature was measured using a YSI Model 85 meter. Turbidity was measured using a HACH Model 2 lOOP

Turbidimeter and pH was measured using an Orion Model 21 OA meter.

Diatom Assemblages

Diatoms were sampled by pulling two rocks, sizes ranging from coarse gravel to cobble, at random from each transect. Rocks were then scraped from a known area using a toothbrush and delimiter and combined into a composite sample per site. This composite sample was homogenized, then split into three sub-samples for chlorophyll a (chl *a),* Ash-free Dry Mass (AFDM), and species identification/enumeration.

Macroinvertebrates

Collection methods followed a modified version of the procedures of EPA's EMAP protocol (EPA, 1998). Macroinvertebrates were collected quantitatively using a Hess sampler. The dimensions of the Hess sampler cylinder were approximately 33 cm in diameter, 41 cm in height with an area of 858 cm2. The mesh size of the inflow window was 1,000 microns and the collecting net was 363 micrOns. Ten samples were randomly collected per stream reach (two per transect) to form one composite sample for each site. Cobbles and other substrate in the Hess sampler were thoroughly scrubbed to wash macroinvertebrates into the collecting net. Macroinvertebrates were preserved in 90 % ethanol and refrigerated for laboratory processing.

Lab Analysis

Water Chemistry

Water samples were analyzed for nutrients. Samples were analyzed for nitrate and nitrite by ion chromatography and colorimetric methods, respectively (EPA methods 300.0, 1979, and 353.2, 1993). These two constituents were added together for this study (NO3+N02). Ammonium nitrogen (NI-Li') concentrations were determined using the phenol-hypochlorite method (EPA method 350.1, 1993). Orthophosphate (o-P) concentrations were determined using the colorimetric methods (EPA method 365.1, 1993). Total phosphorus (TP) concentrations were determined using persulfate digestion and colorimetric methods (EPA method 365.1, 1993). Water samples for temporal samples were analyzed using different methods. Orthophosphate concentrations were determined using the ascorbic acid method (Wetzel and Likens 1991). Nitrate+nitrite nitrogen concentrations were determined using the cadmium reduction method (Jones 1984). Ammonium nitrogen concentrations were determined using the phenol-hypochlorite method (Wetzel and Likens 1991). All nutrient concentrations were analyzed using the Milton Roy® Spectronic 401. The 1st year water samples were analyzed by the City of Portland BES Chemistry Lab. The 2nd year's water samples were analyzed at Portland State University.

Diatom Analysis

Diatom samples were digested with concentrated sulfuric acid and potassium dichromate, rinsed with deionized water repeatedly until pH was approximately neutral, then mounted on slides using Naphrax® high resolution mounting medium. Using a Nikon Eclipse E600 scope, transects were scanned until 500 diatom valves were identified to the species level at 1000 X magnification. Patrick and Reimer (1966, *1975)* and Krammer and Lange-Bertalot (1986, 1988, 199la, 1991b) were used as primary references for diatom taxonomy. Chl a concentrations were determined using fluorometric methods corrected for phaeophytin (APHA 1992). Extraction of chl a was done using *95%* acetone and then read using a Turner® Model 450 fluorometer. AFDM was determined using standard methods (APHA 1992). Dry mass of sample material was determined before and after oxidation at 5000C. A list of diatom metrics were calculated based on the literature (Table 2).

Macroinvertebrate Analysis

Macroinvertebrates were processed in the laboratory using standard methods for sorting and identification (EPA, 1999). Macroinvertebrates were subsampled using a 300-organism subsample size. Composite samples were spread evenly across a standard subsampling tray and random grids were selected and counted until a minimum of 300 organisms was achieved. A dissecting microscope was used for sorting and identification. After reaching 300 macroinvertebrates, the rest of the grid was counted to achieve full count of the grid. If the composited sample contained less than 300 macroinvertebrates, then the entire sample was counted. Macroinvertebrates were identified using Merritt and Cummins (1996). The insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) were identified to the genus level where possible. All other macroinvertebrates were identified to the family or order level. All samples and specimens were labeled, preserved and stored for quality control. A list of macroinvertebrate metrics were calculated based on the literature (Table 3).

Data Analysis

Stream sites were classified based on EPT or diatom assemblage composition using the program TWINSPAN (two-way indicator species analysis) (Hill et al. *1975).* This divisive cluster method starts with all sites as one group and repeatedly divides it into two smaller groups based on overall differences (e.g. top-down) (van Tongeren 1995 (Figure 3). Univariate analyses (ANOVA, or Kruskal-Wallis and multiple comparison Tukey Tests) were used to assess differences among classification groups (Zar 1999). The same univariate analyses were used for stream comparisons.

Temporal variation of diatom species assemblages in one urban and one rural stream sites and their relation to environmental variables were summarized using canonical correspondence analysis (CCA). CCA is a multivariate ordination technique for unimodal species data (ter Braak *1995).* All stream sites can be ordinated along a few ordination axes based on species composition and then species distribution patterns can be directly related to major environmental variables. Environmental variables were LOG10 transformed to normalize their distribution, except percentage data and pH, prior to this analysis. Proportional data were transformed by first taking their square root then the arc sin. Because some environmental variables are highly correlated and thus do not contribute unique information, forward selection and Monte Carlo permutation tests were used to select a set of environmental variables which correlate best with species assemblages (ter Braak and Smilauer 1998). A few of the variables which were not selected by this procedure, but were important to this study such as urban land-use, were also included in the final analysis. Unrestricted global Monte Carlo permutation tests were used to test the significance of the first two CCA axes (999 permutation). Species data were standardized by relative abundance. Species that had a relative abundance <1% were not included in this analysis. CCA was performed using the computer software CANOCO for windows (v. 4)(ter Braak and Smilauer 1998)

QA/QC

The quality of identification and enumeration of both macroinvertebrates and diatoms was first assessed internally within the research group. Samples identified by one analyst were re-examined by another independent analyst for consistency within the research group. Discrepancy between the two analysts was discussed and reconciled if the two could reach an agreement. If agreement could not be reached within the research group, the samples in question were sent to local experts for positive identification and discrepancy was reconciled. Approximately 10% of macroinvertebrate samples were randomly selected from each year's samples and sent to a local expert with extensive experiences on benthic macroinvertebrates in Oregon streams. The discrepancy in taxa identification and enumeration was reconciled if it was detected.

Results

Comparison between Urban and Rural Streams

Macroinvertebrates

Macroinvertebrate assemblages were significantly different between the urban streams and rural streams. Of 22 macroinvertebrate metrics, 14 metrics were significantly different among streams based on 1999 summer data (Table 4). Mean richness of total No. taxa, No. EPT taxa, No. Ephemeroptera, No. Plecoptera, and No. Tricoptera in the two urban streams were all significantly lower than those in the rural streams. Percent of EPT in Clear Creek (mean = *50 %)* was significantly higher than that in Johnson Creek (mean = 30%). Percent of Diptera in Tryon Creek (mean = 48 %) was significantly higher than that in Clear Creek (mean = 13 %). Percent of Diptera, however, was also high in Deep Creek (mean =*45 %).* EPT taxa in Johnson Creek were characterized by pollution-tolerant taxa. Both % Hydropsychidae to Tricoptera and % of Baetidae to Ephemeroptera in Johnson Creek were significantly higher than those in Clear Creek (Table 4). Percent of scrapers in Clear Creek (mean = *52 %)* was significantly higher than those in Johnson Creek (mean = 31 %) and Tryon Creek (4 %). Total macroinvertebrate density (number/rn2) in Tryon Creek was significantly lower than the two rural streams (Table 4).

A similar pattern was observed in 2000 summer data. For example, mean richness of total No. taxa, No. EPT taxa, No. Ephemeroptera, No. Plecoptera, and No. Tricoptera in Clear Creek was significantly higher than two urban streams (p = 0.000l) (Table *5)*. Percent of EPT in Clear Creek (mean = 42%) was significantly higher than that in both Johnson Creek (mean = 27%) and Tryon Creek (mean = 20%).

Diatoms

Diatom assemblages were also significantly different among four streams (Table 6). Data collected in 1999 showed that diatom assemblages in Clear Creek were dominated by *Achnanthes deflexa* (36 %) while the assemblages in Tryon Creek were dominated by *A. lanceolata* (3*5 %).* Siltation index in Clear Creek was significantly lower than those in Deep Creek and Johnson Creek. Diatom assemblages in Tryon Creek were characterized by significantly higher proportion of nitrogen tolerant taxa (77 %), ~-mesosaprobous taxa *(56 %),* and eutraphentic taxa (81 %). A similar pattern was observed in 2000 data (Table 7).

Environmental Variables

Several water quality and physical habitat variables were significantly different between the urban and rural streams (Table 6, 7). For example, both 1999 and 2000 data showed that conductivity in Johnson Creek and Tryon Creek was significantly higher than that in Clear Creek and Deep Creek (only 1999 data). Total RBP scores, a measure of physical habitat condition, in the two rural streams, were significantly higher than those in the two urban streams (Table 6).

Comparison among Biota-based Stream Groups

EPT-based Stream Site Classification (1999 data)

TWINSPAN classified all stream sites into five groups based on EPT taxa composition (Table 8a). Group V only has one site (TC 013) and thus was not included in statistical comparison. Group I consists of all Johnson Creek sites (n = 10) including five of six headwater sites outside the Urban Growth Boundary. Other sites include one site in Crystal Spring (JC 002), one site near the Leach Botanical Garden (JC 004), and one site in Kelly Creek (JC 011). Group Ills also dominated by Johnson Creek sites (71%). A total of four sites in Tryon Creek were also classified into this group. Most of the Johnson Creek sites in this group are located in the middle portion of the creek. Group III consists of about an equal number of Johnson Creek and Tryon Creek sites. Most of the Johnson Creek sites are located downstream. Group IV was dominated primarily by the two rural stream sites (94.4%) including all Clear Creek sites.

ANOVA and multiple comparison tests showed that the stream sites in Group IV were significantly different from other three groups in all five taxa richness measures, % Ephemeroptera, % Hydropsychidae to Tricoptera, and % Baetidae to Ephemeroptera (Table 9). Other three groups were different in several metrics. For example, % Diptera was the highest in Group III (44%) compared to Group I (23%) and 11(32%). However, the difference was not statistically significant *(p>0.05).* The sites in Group III did have significantly lower % Gastropoda (9%) than that in Group I (3 3%) and II (27%).

EPT-based Stream Site Classification (2000 data)

TWINSPAN classified all stream sites into four groups based on EPT taxa (Table 8b). Group I consists of all Clear Creek sites (n=12) and one Tryon Creek site (TC 008). Group II is dominated by Johnson Creek sites (76%) including all *5* headwater sites outside the Urban Growth Boundary. A total of five sites in Tryon Creek were classified into this group. Group III was also dominated by the Johnson Creek sites (66%). Most of the Johnson Creek sites are located in the downstream. Group IV consists entirely of Tryon Creek sites.

ANOVA and multiple comparison tests showed that the stream sites in Group I were significantly different from other three groups in all five taxa richness measures, % Plecoptera, and % dominant taxon (Table 10). Because the group number was assigned arbitrarily for 1999 and 2000 classifications, this group corresponded to Group IV in 1999 classification. Like the results of the 1999 classification, the differences among the rest of three groups were not statistically significant for most of the metrics. However, % of Hydropsychidae to Tricoptera was significantly different among the three groups. This measure increases from Group IV (0%) to Group II (67%) to Group III (97%). Group III also had significantly higher % Baetidae to Ephemeroptera than other two groups.

Diatom-based Stream Site Classification (1999 data)

TWINSPAN classified all stream sites into five groups based on diatom species composition (Table 11 a). Group I consists of six Johnson Creek sites and one site each from Clear Creek and Deep Creek. Group II was primarily dominated by Johnson Creek sites. Group III consists of a mixture of Johnson Creek sites and sites from the .two rural streams. Group IV was dominated by the sites from Clear and Deep Creek. Group V consists mainly of Tryon Creek sites.

ANOVA and multiple comparison tests showed that the stream sites in Group V. dominated by Tryon Creek sites, were significantly different from other four groups in % a-mesosaprobous taxa, % of pollution less tolerant taxa, % of pollution sensitive taxa, and pollution index (Table 12). Interestingly, Group IV, dominated by rural stream sites, was not significantly different from other groups in most of the metrics.

Diatom-based Stream Site Classification (2000 data)

TWINSPAN classified all stream sites into four groups based on diatom species composition (Table 1 lb). Group I consists of eight Johnson Creek sites, one site from Clear Creek, and two sites from Tryon Creek. Group II was primarily dominated by Tryon Creek sites (n=13) with several Johnson Creek sites (n=~4). Group III consists of all six Johnson Creek sites. Group IV was a mixture of the sites from Clear and Johnson Creek.

ANOVA and multiple comparison tests showed that the stream sites in Group IV were significantly different from Group I and II in pollution index (Table 13). The sites in this group had the highest proportion of pollution sensitive taxa. The patterns were unclear among these groups for other metrics (Table 13).

Comparison among Biota-based Stream Groups within Johnson Creek

EPT-based Stream Site Classification (1999 data)

TWINSPAN classified all Johnson Creek sites into four groups based on EPT taxa (Table 14a). Group IV only has one site (JOH 016) and thus was not included in statistical comparison. Group I consists of four sites which are all located downstream. Group III includes more than half of all sites including all headwater sites located outside of the Urban Growth Boundary.

ANOVA and multiple comparison tests showed that the stream sites in Group I had a significantly higher No. Tricoptera taxa than other two groups (Table *15)*. Total density and EPT density in Group I were also significantly higher than Group III. In general, however, there were no significantly difference among three groups for most of the metrics.

EPT-based Stream Site Classification (2000 data)

TWINSPAN classified all Johnson Creek sites into four groups based on EPT taxa (Table 14b). ANOVA and multiple comparison tests showed that the stream sites in Group I had a significantly higher No. Tricoptera taxa than the other three groups (Table 16). The sites in this group also had significantly higher No. EPT taxa, % Hydropsychidae to Tricoptera, and % Baetidae to Ephemeroptera than Group IV. In general, however, there were no significantly differences among three groups for most of the metrics.

Diatom-based Stream Site Classification (1999 data)

TWINSPAN classified all stream sites into three groups based on diatom species composition (Table I 7a). ANOVA and multiple comparison tests showed that the stream sites in Group I were significantly different from the sites in Group III in % alkaliphilous taxa, % halophilous taxa, % a-mesosaprobous/polysaprobous taxa, and % of pollution tolerant taxa (Table 18).

Diatom-based Stream Site Classification (2000 data)

TWINSPAN classified all stream sites into three groups based on diatom species composition (Table 1 7b). ANOVA and multiple comparison tests showed that the stream sites in Group I were significantly different from the sites in other two groups in three dominant species, % mesotraphentic taxa, and % meso-eutraphentic taxa (Table 19).

Comparison of Temporal Variation of Biota and Environmental Variables between an Urban and a Rural Stream Site

Macroinvertebrates

Assessment of the temporal variation of macroinvertebrates in Johnson Creek and Clear Creek was hampered by difficulty in sampling macroinvertebrates during the wet season when stream water levels were high. Based on limited sampling points, it is evident that No. EPT taxa was consistently higher in Clear Creek than in Johnson Creek despite seasonal variation of the metric (Fig. 2).

Diatom Assemblages

More complete temporal diatom data were collected in both Clear Creek and Johnson Creek due to ease of collecting diatom samples. Physical, chemical, and diatom assemblages were different between the urban and rural streams. Water quality variables such as conductivity, ortho-phosphate, and N03+N02 were greater and more variable at the urban than the rural site throughout the year (urban: conductivity *=175.9 i.tSlcm,* ortho-phosphate =0.06 mg/L, N03-I-N02 =3.64 mg/L; rural: conductivity *=55.4* ~tS/cm, ortho-phosphate =0.0 1 mg/L, N03+N02 =0.35 mg/L. Turbidity was also greater at the urban site, averaging 6.1 NTU during the year, except in the month of January and was more variable than at our rural site that averaged 3.3 NTU.

Common diatom species at the urban site were most correlated with stream discharge, nutrients, and conductivity. Relative abundance of *pinnata* was most correlated with conductivity and average monthly discharge. The species *C. placentula* was most correlated with average monthly discharge, stream temperature, and o-phosphate. Relative abundance of *A. lanceolata* was highly correlated with average monthly discharge (r=0.70). Conductivity was highly correlated with nutrient concentrations (ortho-phosphate: r=0.65 and N03+N02: 17=0.76).

Species common at the rural site correlated most with nutrients, although stream discharge data were not available for this site. Relative abundance of A. *deflexa* was correlated with phosphorus concentrations (TP: r=0.53, ortho-phosphate: r=0.49). *Cocconeisplacentula* was most correlated with stream temperature, pH, and conductivity (r=0.58, 0.53, and 0.35). Relative abundance of A. *lanceolata* was correlated with N03+N02 concentrations (r=0.47).

The 1st two CCA axes explained about 28% of the variation for diatom assemblages at the urban and rural sites throughout the year. The species-environmental correlations for axes 1 and 2 of CCA were high (r=0.91 and 0.80 respectively) (Figure 3). Collectively, the selected environmental variables explained 49.2% of the variation of diatom species distribution captured by the lst two axes. Global Monte Carlo permutation tests showed that both axes were statistically significant (p<0.0l).

The 1st axis may represent an urban land use gradient. Diatom assemblages throughout the year at the rural site ordinated on the left side of the 1st axis based on species composition and their relation to measured environmental variables while those at the urban site were on the right side of the axis. This axis was highly correlated with conductivity (r=0.89), ortho-phosphate (r=0.79), and N03+N02 (r=0.8 1). The 2nd axis was weakly correlated with stream temperature (0.39) and turbidity (r=-0.3 7). However, the 2nd axis may represent how diatom assemblages change over time. Both urban and rural sites varied along the 2nd axis. Sites sampled at corresponding times of year had similar diatom assemblages demonstrating a seasonal pattern.

Discussion

Spatial Variation between Urban and Rural Streams

Macroinvertebrates

It is expected that macroinvertebrate assemblages are significantly different between urban and rural streams. Our two-year data clearly show that macroinvertebrate assemblages in urban streams are different from those in rural streams in richness measures, composition measures, tolerance measures, feeding measures, and biomass measures. The macroinvertebrate assemblages in urban streams are characterized by low overall taxa richness and taxa richness of the three sensitive aquatic insect orders (Ephemeroptera, Plecoptera, and Tricoptera) compared to rural streams. EPT composition in Johnson Creek was significantly lower than that in Clear Creek. Although approximately 30% of the macroinvertebrate assemblages in Johnson Creek is EPT taxa, this group was characterized by pollution-tolerant taxa. For example, both % Hydropsychidae to Tricoptera and % of Baetidae to Ephemeroptera in Johnson Creek were significantly higher than those in Clear Creek. Both metrics are expected to increase as perturbation increases (Barbour et a!. 1999). Percent of scrapers in Clear Creek was significantly higher than those in Johnson Creek and Tryon Creek. Total macroinvertebrate density (number/rn2) in Tryon Creek was significantly lower than the two rural streams.

Our results are consistent with previous research reports. Quinn et a!. (1997) found that EPT taxa densities in forest streams were 2-3 fold higher than in pasture streams in which the macroinvertebrate assemblages were dominated by chironomids, snails, and worms. Stanley and James (1997) found that streams in an urbanized portion of a watershed contained macroinvertebrates dominated by pollution tolerant taxa. In contrast, streams in non-urbanized areas were dominated by pollution sensitive taxa, such as Ephemeroptera and Trichoptera. Lenat and Crawford (1994) found that invertebrate taxa richness and the number of unique invertebrate species indicated moderate stress (fair water quality) at the agricultural site and severe stress (poor water quality) at the urban site. The urban site was characterized by low species richness for most groups and very low abundance values. Their study also showed that dominant macroinvertebrate groups shifted from Ephemeroptera at the forested site, to Chironomidae at the agricultural site, and Oligochaeta at the urban site.

Diatoms

Diatom assemblages were also significantly different among urban and rural streams. Data collected in 1999 showed that diatom assemblages in Clear Creek were dominated by *Achnanthes deflexa* while the assemblages in Tryon Creek were dominated by *A. lanceolata.* The species *A. deflexa* is known to prefer oligotrophic conditions. Using both field survey and laboratory experiments, Klotz et al. (1976) showed that A. *deflexa* decreased in stream sites highly polluted by effluent input from a sewage treatment plant. *A. lanceolata* is considered an indicator of eutrophic waters (Lange-Bertalot 1979 and Kelly and Whitton *1995). A. lanceolata* has been found to increase with elevated nutrient concentration in unshaded California streams (Hill and Knight 1988). Siltation index in Clear Creek was significantly lower than those in Deep Creek and Johnson Creek. This index (Bahls 1993) was calculated as a summation of the relative abundance of all motile diatoms (defined as diatoms with raphes in both valves). Motile diatoms such as *Nitzschia* and *Surirella* are often abundant in streams dominated by fine substrates and thus can reflect sedimentation in streams. The highest of the index value was associated with the stream group with the highest % of watershed agricultural land use in Mid-Atlantic Highland streams (Pan et al. 1999). It is interesting that the diatom-based analyses often reveal significant differences between Clear Creek and Tryon Creek, but not between Clear Creek and Johnson Creek. Agricultural practices in the Clear Creek Watershed may enrich the nutrient levels in Clear Creek. Based on dominant diatom species and relatively higher diatom metric values, Tryon Creek seems to be more severely impacted by organic pollution than Johnson Creek.

Environmental Variables

Urban streams and rural streams were also significantly different in water quality and physical habitat conditions. Our data showed that urban streams are characterized by relatively higher conductivity. Conductivity has been suggested as a surrogate measure of human disturbance, such as urbanization, in Pacific Northwest streams (Welch et al, 1998). Bryant (1995) found that baseflow conductivity related well to impervious surface area in Puget Sound lowland streams (r2=0.83). Increases in conductivity associated with impervious urban areas may also be accompanied by higher metal inputs. Bryant (1995) reported that conductivity, total zinc concentrations, and % of impervious areas were highly correlated. Leland (1995) found that conductivity correlated well with algal species distributions (r= -0.78) in Columbia Plateau streams of the Yakima Basin and elevated algal biomass in agricultural watersheds where conductivity was high (>500 jiS/cm at 250C). In a study examining 25 Oregon Willamette streams, Carpenter and Waite (2000) reported that conductivity separated urban and agricultural streams from forested sites.

Urban streams are also characterized by poor physical habitat condition. The visual- based habitat assessment includes multiple aspects of streams, such as channel morphology, substrate composition, and riparian conditions (Barbour et al. 1999). The scores indicated that overall physical habitat conditions in Johnson Creek were categorized as marginal.

Temporal Variation between Urban and Rural Streams

Our limited temporal data suggest that the sampled urban stream site and rural stream site were different in the macroinvertebrate metrics, diatom assemblages, and environmental variables over time. Species and environmental parameters in streams have high seasonal variability (Moore 1978), which necessitates the evaluation of these relationships over time. Diatom assemblages in both urban and rural sites showed substantial seasonal variation. However, the two assemblages did not overlap in the ordination space over the time, indicating species assemblages were different throughout a year. The 1st CCA axis that separated the urban and rural sites was highly correlated with conductivity and nutrients which is consistent with the findings in spatial comparison among urban and rural streams in summers. At the urban site, the common species *C. placentula* and *F. pinnata* decreased during the wet season. The species A. *lanceolata* increased during the wet season and was highly correlated with discharge. At the rural site, both *C. placentula* and A. *lanceolata* increased during the wet season. Both of these species are adnate, which is a mechanism of attachment close to substrate, and are thought to be resistant to physical disturbance such as high flows during the wet season (Peterson 1996, Biggs et a!. 1998, Rounick and Gregory 1981).

The hydrologic alteration in urban systems causing increased peak flows (Booth 1991) may be too much for even these resistant taxa to persist. Stevenson (1990) found that storms were strongly associated with benthic algal community change in a mid-western stream and hypothesized that severe storms that overturn substrate in streams may have a significant effect. A study performed in experimental stream channels found that early successional communities were associated with a sparsely populated monoraphid diatom *(A. minutissima)* (Peterson and Stevenson 1992). Conductivity showed a distinct seasonal pattern decreasing during the wet season, probably due to dilution. A similar pattern in USGS's NAQWA program was found in agricultural watersheds of the Willamette Basin (USGS 1995).

Stream Site Classification

Stream conditions may vary among streams but also within the same stream. Spatial variability of the stream conditions within urban streams may be used to assess effectiveness of current or past restoration efforts or other management practices. Recognizing spatial variability of the stream conditions may also help to prioritize restoration efforts. Since biota can integrate overall environmental conditions in streams, biota-based stream site classification may better reflect current stream ecological conditions. Two approaches were used for this study with different aims. First of all, we classified all urban and rural stream sites based on either EPT composition or diatom species composition. It is always scientifically and politically difficult to identify 'reference conditions' for urban streams (Hughes 1995). The main objectives for this approach are to use good rural sites as 'reference' sites and to match some "good" urban sites with these good rural sites if a 'working' reference condition, such as Clear Creek is acceptable. Secondly, we classified all Johnson Creek sites based on either EPT or diatom species composition. Such a classification would help to rank site conditions according to biological assemblages. No further interpretation of each group was made in this report. We intend to provide 'raw' information for management.

Limitation of the Study

This study mainly focuses on stream bioassessment. Although biota and selected environmental variables were significantly different between urban and rural streams, cause and effect relationships can not be derived from this study. Biota can integrate overall environmental conditions and are sensitive to environmental changes. Therefore biota can be used as an effective tool to monitor environmental degradation. To identify the potential cause, especially multiple causes, a study with a different design may be needed.

It is unclear how different taxonomic resolution for the different macroinvertebrate taxa groups would affect overall conclusions. Macroinvertebrate assemblages were identified into different taxonomic levels. All EPT taxa were identified to the genus level whenever possible. For all biota-based classification, only EPT taxa were used. However, urban streams are commonly dominated by Diptera, Oligochaeta, and Gastropoda. It is more difficult to identify these taxa to fine taxonomic levels.

Conclusions and Recommendations

Both macroinvertebrate and diatom assemblages were significantly different between urban and rural streams. Several benthic metrics may be used effectively for urban stream assessment. Our data showed that richness metrics showed consistent differences between urban and rural streams for two years. These metrics are easy to compute and interpret. We recommend using these simple metrics for future monitoring and assessment. Biota, as a 'moving target', vary both spatially and temporally. Changes in biota may result from both natural and anthropogenic effects. Therefore we recommend establishing long-term monitoring sites in both rural and urban streams with other long-term monitoring stations, such as USGS gaging stations. We recommend that BES may include stream bioassessment as a part of their routine operation. In other words, we suggest that BES hire a staff with graduate-level training in macroinvertebrate field sampling and lab analysis and thus routine biomonitoring of the urban streams can be done in 'house' and a long-term database can be developed and maintained.

It must be cautious to interpret the significant differences in biota between urban and rural streams. Both natural and anthropogenic factors may attribute the significant differences in biota between urban and rural streams (Walker 2001, Hoy 2001). The actual mechanisms of how the urban streams degrade may not be so simple to reveal. We recommend that BES continue to plan and conduct multi-disciplinary watershed studies to identify major causes for urban stream degradation. Biota in urban streams can be used as an effective endpoint.

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Table 1. List of the sample sites in Johnson Creek, Tryon Creek, Clear Creek, and Deep Creek.

A. Johnson Creek Watershed

Site ID	**Site Location**
JOHOOI	JC@Milport Rd. (temporal site)
JOHOO2	Crystal Springs (mouth@JC park)
JOHOO3	JC before Crystal Springs (JC park)
JOHOO4	JC@Leach Got. Garden (122nd *&* Foster)
JOHOO5	JC@Bluff Rd. (near headwaters)
JOHOO6	Crystal Springs~West Moreland
JOHOO7	Crystal Springs~Reed College (headwaters)
JOHOO8	JC@82nd Bridge
JOKOO9	JC@Fish Ladder (Tideman Johnson)
JOHOIO	JC@Covered Bridge (just past Leach Got.)
JOHOI *I*	Kelly Ok. (mouth)
JOHOI2	JC before Butler (around 190th)
JOHOI3	JC after Butler (around 190th)
JOHOI4	JC@Regner Rd. (USGS gaging station)
JOHOI5	JC@Brookside (about 112th)
JOHOI6	Mitchell Ck. (162nd)
JOHOI7	JC@JC Gresham Park (Powell)
JOHOI8	JC@mouth (off of 99E)
JOHOI9	JC after Crystal Springs (JO park)
JOHO2O	JC@Bell Ave. (off of JO Blvd.)
JOHO2I	JC@142nd
J0H022	JC@155th
J0H023	JC@Towle (off of Spring Water Corridor)
J0H024	JC@252nd
J0H025	JC@282nd
J0H026	JC@307th (Orient Dr.)
J0H027	JO headwaters@Cottrell Rd.
J0H028	JC@267th
J0H029	JC@Tideman Johnson Park (riffle below sewer reconstruction)
JOHO3O	JC@86th (approximate location)

B. Tryon Creek Watershed

Site ID	Site Location
TRYOOI	Tryon Creek near mouth (Stampher Rd.)
TRYOO2	Tryon Creek N. of Iron Mt. Bridge (Tryon State Park)
TRYOO3	Nettle Creek (100 m above Iron Mt. Bridge)
TRYOO4	Tryon Creek @Marshall Pk.
TRYOO5	Tryon Creek below Red Fox Br.
TRYOO6	Tryon Creek below Obies Br.
TRYOO7	Tryon Creek @ Beaver Br.
TRYOO8	Tryon Creek above Arnold Ck.
TRYOO9	Arnold Ck. (mouth) before Tryon Creek
TRYOIO	Tryon Creek @ 4th Ave. (Tryon State Park)
TRYO1 I	Tributary @ 4th Ave. before Tryon Creek
TRYOI2	Tributary @ Marshall Pk.
TRYOI 3	FaIling Ck. Above restoration site
TRYOI4	Tryon Creek before Falling Ck (about 200m below 1-5)
TRYOI 5	Tryon Creek (near mouth) @ Sewage Treatment Plant

C. Clear Creek Watershed (Clackamas Basin)

Site ID	Site Location
CLEOOI	Clear Cr. @Carver Pk. (mouth)
CLEOO2	Clear Cr.@15061 S. Hattan Rd.
CLEOO3	Clear Cr. @Clear Acres Dr. (off of Hattan Rd.)
CLEOO4	Clear Or.@Fischers Mill Rd.
CLEOO5	Clear Cr.@Mckenzie Lane (off Matoon Rd)(temporal site)
CLEQO6	Clear Cr.@S. Redland Rd.
CLEOO7	Clear Cr.@Redland/Matoon Br.
CLEOO8	Clear Cr. @Matoon Rd.
CLEOO9	Clear Cr.@lower Metzler Pk
OLEO1O	Clear Cr. @upper Metzler Pk (campsite)
CLEOII	ClearCr.@211 Br.
CLEOI2	Clear Cr. @Bezinger Rd.

D. Deep Creek Watershed (Clackamas Basin)

Site ID	Site Location
DEEOOI	Deep Cr.@Aemisegger Rd.
DEEOO2	Deep Cr.@Holst Rd.
DEEOO3	Deep Cr.@Trestel Glen (off of 1-224)
DEEOO4	Deep Cr.@224 Deep Creek Br.
DEEOO5	Trib. Deep Cr. @Trestle Glen
DEEOO6	Tickle Creek@Tickle Creek Br.
DEEOO7	Deep Cr.@211 (Eagle Creek Sandy Highway)
DEEOO8	Trib. Deep Cr.@21 I (Eagle Creek Sandy Highway)

Tryon Creek flows through a 400 ft. long concrete culvert under Highway 43 (State Street) in Lake Oswego, approximately 1000 ft. upstream from the creek’s confluence with the Willamette River. The rock- constructed banks are choked with invasive Himalayan blackberry and English ivy. Steel “baffles” in the floor of the culvert were intended to allow for fish passage.