ASSESSMENT OF MACROINVERTEBRATE COMMUNITIES IN RELATION TO LAND USE, PHYSICAL HABITAT, AND WATER QUALITY IN THE TUALATIN RIVER BASIN, OREGON

FINAL REPORT

Prepared for

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EXECUTIVE SUMMARY

- Macroinvertebrate communities, physical habitat, and water chemistry were sampled from 63 stream reaches in the Tualatin River basin in fall 2001 to assess the condition of macroinvertebrate communities in relation to land use patterns and instream physicochemical conditions. Thirty seven low-gradient and 26 high-gradient reaches were sampled.
- High-gradient reaches were assessed using multimetric analysis, followed by correlation of environmental variables with multimetric scores to examine the ability of this metric set to reflect the condition of high-gradient reaches in the basin in relation to environmental conditions. Relationships between environmental conditions and benthic community structure in low-gradient reaches were examined with multivariate pattern analysis and indirect gradient analysis, as well as with a set of selected metrics that was used to rank low-gradient reach conditions.
- Community composition differed considerably between high and low-gradient reaches. High-gradient reaches ranged widely in their condition; major gradients in community condition were strongly related to land-use types and a number of instream environmental variables. High-gradient reaches occurring primarily in forested catchments were characterized by high EPT (mayfly, stonefly, and caddisfly taxa) richness, low proportions of tolerant organisms, high sensitive-taxa richness, low collective tolerance to disturbance, and high total taxonomic richness. These conditions ranged to the other extreme in heavily urbanized areas, where taxonomic richness was low, collective community tolerance to disturbance was high, and EPT richness was low. Metric values were highly correlated with a number of environmental variables indicative of impairment, indicating that the metric set employed is an effective assessment tool for use on macroinvertebrate community data from high-gradient reaches in the Tualatin River basin.
- Low-gradient reaches showed much less variability in community composition. These reaches occurred exclusively in areas dominated by urban or agricultural land uses. Low-gradient reaches were characterized by low taxonomic richness, few or no EPT taxa, high dominance by a few taxa, large proportions of oligochates, chironomids, and mollusks, and a large proportion of tolerant organisms. Multivariate analysis and indirect gradient analysis indicated that invertebrate community conditions in low-gradient reaches did recognizably vary with land use and instream physical conditions, particularly substrate, but also with dissolved oxygen, as the overall community tolerance to impairment increased with decreases in the condition of these measured variables.
- Our data indicate that 2001 drought conditions may have further degraded macroinvertebrate communities in more rural areas where, in 2000, higher taxonomic richness and, in particular, higher EPT taxonomic richness were measured.

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INTRODUCTION

The Tualatin River basin has undergone steady agricultural, forestry, industrial, and urban development for more than 100 years. This steadily increasing human influence on the basin has degraded water quality and physical habitat of surface waters, and has altered the hydrology of the basin. Concerns over the effects of these changes on aquatic life have led to basin-wide assessments of fish and macroinvertebrate communities in recent years (Friesen and Ward 1996, Cole 2000, Leader 2001).

In September 2000, Clean Water Services initiated a large-scale assessment of macroinvertebrate communities in the upper and middle Tualatin River Basin to characterize the condition of benthic biological communities. The resulting study ranked the biological condition of each of 44 stream reaches and provided a baseline data set for these conditions throughout much of the basin (Cole 2000). While providing valuable information, the study was limited by a lack of analytical tools and environmental data that could allow low-gradient, glide-dominated streams to be evaluated independently of high-gradient, riffle-dominated streams. Consequently, all streams were ranked in relation to one another without regard to the physical characteristics of the stream reach or its surrounding landscape.

Macroinvertebrate communities are strongly influenced by physical differences among habitats, both naturally occurring and human-induced. Characterizing these relationships between environmental factors and invertebrate communities is essential to understanding how aquatic communities in a particular geographic area are structured by the physical and chemical makeup of their environment and how they are affected by alterations to those conditions. The inclusion of habitat variables in a macroinvertebrate assessment allows these relationships to be explored and allows comparisons of biological conditions among sites to be made with consideration to gradient and other natural physical features that shape benthic community structure. In recent years, a number of studies have used ordination and correlation to examine such relationships (Reece and Richardson 2000, Marchant et al. 1999, Turak et al. 1999, Tate and Heiny 1995), including recent work by Oregon State University in the Willamette basin.

The current lack of analytical tools to evaluate the condition of macroinvertebrate communities in low-gradient, Tualatin valley floor streams is primarily the result of a lack of relatively undisturbed reference conditions against which other, more impaired reaches can be compared. In contrast to these low-gradient, valley floor streams, higher gradient streams still occur in relatively undisturbed, mature second-growth forests on the fringes of the Tualatin River basin, and elsewhere throughout the Willamette valley and western Oregon. Consequently, both multimetric and multivariate tools have been developed for analysis of these higher gradient streams.

Both multimetric and multivariate approaches evaluate the sampled community by comparing observed conditions to what conditions or taxa are expected to occur in the absence of disturbance. Multimetric analysis uses a set of metrics, or community attributes, that are known to be responsive to stream degradation (Karr and Chu 1999). Each of these metrics is calculated from the sample data and then converted to a standardized score using scoring criteria. Scoring criteria are developed from examining relationships between individual metric scores and an indicator of impairment (e.g., effective impervious area) across a range of impairment levels, including undisturbed reference conditions. The standardized scores are then added to produce the final multimetric score. Multivariate analysis uses multivariate statistics and reference condition data to produce models that predict what taxa should occur at a site of a given stream type and location in the absence of impairment. The observed taxa list is then compared to what is expected to occur in the absence of disturbance to produce an observed/expected (O/E) score. Both of these tools require appropriate reference reaches for proper development and application (e.g, Hawkins et al. 2000).

In fall 2001, we conducted an expanded study of macroinvertebrate communities in the Tualatin River basin. In contrast to the work conducted in 2000, this study examined high-gradient (>1.5% stream slope) and low-gradient (<1.5% stream slope) stream reaches independently and included physical habitat assessments. These enhancements to the study allowed us to examine relationships between environmental conditions and patterns in macroinvertebrate community structure by analyzing high-gradient reaches using existing multimetric analysis tools, and low-gradient reaches using multivariate pattern analysis (ordination) and indirect gradient analysis. The objectives of this study were to 1) assess the condition of macroinvertebrate communities using a multimetric approach when applicable (high-gradient reaches), 2) identify relationships between environmental conditions and macroinvertebrate community conditions when needed (low-gradient reaches), and 3) evaluate the ability of the current sampling effort to accurately characterize benthic conditions by resampling a number of reaches assessed in 2000. Because only high-gradient streams had appropriate reference conditions in the basin and multimetric tools have been developed for these types of streams in western Oregon, a secondary objective of the study was to evaluate the effectiveness of the current western Oregon metrics at accurately classifying macroinvertebrate community condition in relation to instream and land-use conditions, rather than developing a new set of potentially redundant metrics.

STUDY AREA

The Tualatin River Basin is located primarily in Washington County, Oregon, with small areas extending into Multnomah, Yamhill, and Clackamas counties. The basin generally drains in a southeasterly direction, with headwaters occurring as far west as the eastern slopes of the Oregon Coast Range (Figure 1). The basin is bound on the north and south sides by the Tualatin and Chehalem mountain ranges, respectively. The Tualatin River empties into the Willamette River just west of Oregon City. Along its course from the Coast Range to the Willamette River, the Tualatin River and its tributaries exhibit a number of physical and hydrologic changes. These changes are due, in part, to the naturally-occurring physiographic variation that occurs in the area, but have been exacerbated by human settlement in the basin.

Streams occurring farther east in the basin are generally characterized by low gradient, heavy sediment loading, seasonal flooding, temperature extremes, and low habitat heterogeneity (ODFW 1995). Streams on the east slopes of the Coast Range and in areas of more topographic relief elsewhere in the western portion of the basin are characterized by higher gradients, larger and more heterogeneous substrate, and more heterogeneous habitat.

METHODS

STUDY REACH SELECTION

Stream reaches sampled in the Tualatin River basin were selected to represent a range of physical conditions and levels of human influence. Maps of riparian zone conditions and dominant stream substrate were used to allocate reaches between different stream types (gravel- and cobble-dominated high-gradient reaches versus sand- and silt-dominated low-gradient reaches) and across a range of land use intensities. Reach selection also was based on ease of access and adequate stream flow, as water conditions at two reaches initially selected for sampling were too low to sample. In total, 63 reaches were selected for sampling: 26 high-gradient (>1.5% stream slope) and 37 low-gradient reaches, ranging from the east slopes of the Coast Range, to near the confluence with the Willamette River (Table 1). Study reaches were located in all of the larger sub-basins, including Fanno Creek, Rock Creek, McKay Creek, East and West Forks of Dairy Creek, Gales Creek, Upper Tualatin River, and Scoggins Creek, and smaller sub-basins including Ayers Creek, Christensen Creek, Burris Creek, McFee Creek, Heaton Creek, Chicken Creek, and Saum Creek.

FIELD DATA COLLECTION

Macroinvertebrate communities, physical habitat, and water chemistry were sampled at each of the 63 study reaches between 5 September and 15 October 2001. First, the study reach was marked and reach length was measured. Each sample reach measured 10 times the average wetted width or 50 m, whichever length was greater. Reach gradient was then measured with a clinometer and percent riffle, pool, and glide habitat was visually estimated. These parameters were used to categorize the study reach as low

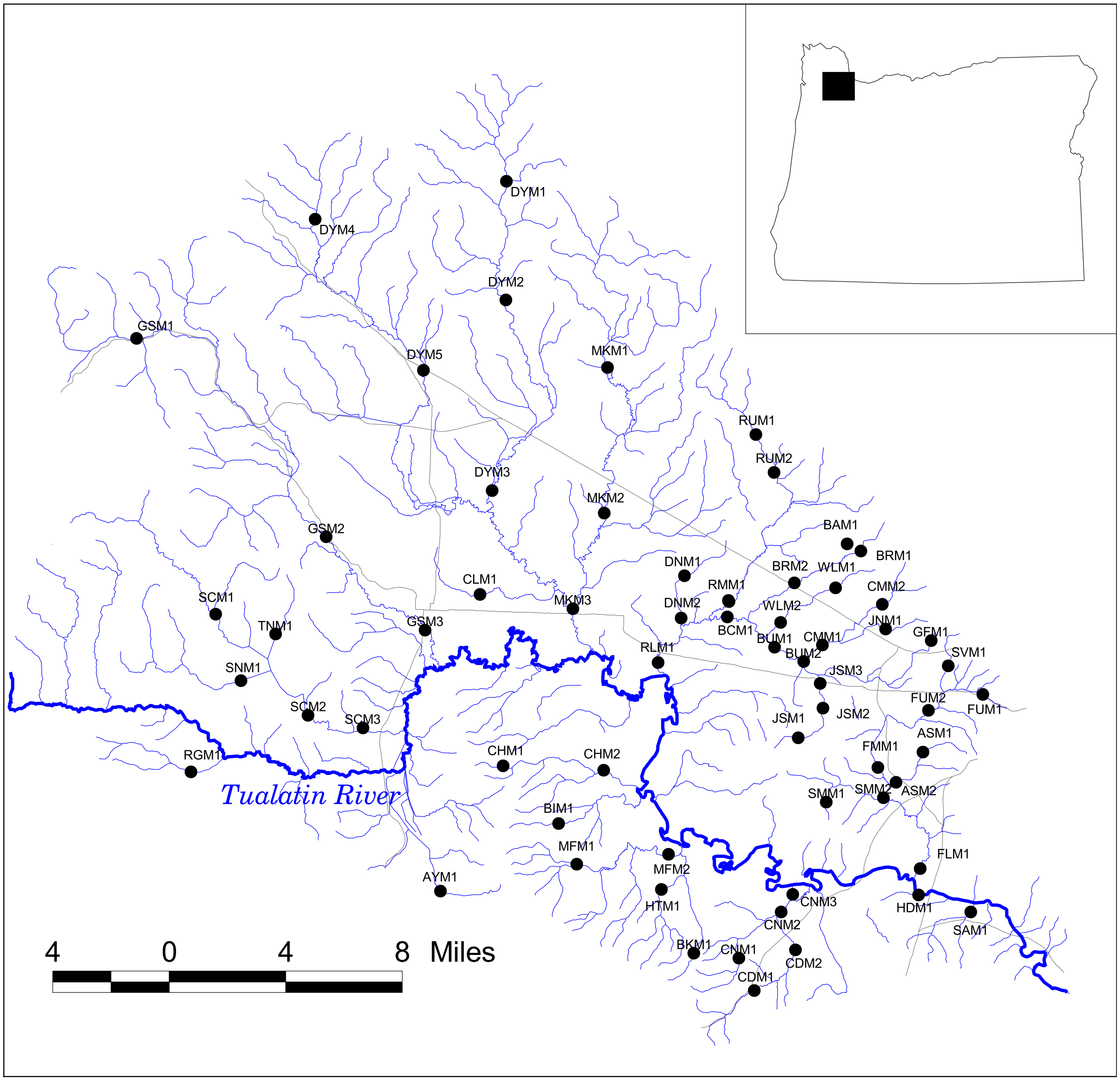

Figure 1. Map of 63 stream reaches sampled for macroinvertebrates, water quality, and physical habitat in the Tualatin River basin, Oregon, fall 2001.

Table 1. Stream reaches sampled for macroinvertebrates in the Tualatin River basin, Oregon, fall 2001.

Stream Name	Study Reach Code	Macroinvertebrate Sampling Location
	Low-gradient Reaches	
Ash Creek (Lower)	ASM2	below Highway 217 (above SW North Dakota St)
Beaverton Creek (Lower)	BCM1	above of Cornelius Pass Road
Beaverton Creek (Upper 1)	BUM1	above 185th Ave
Beaverton Creek (Upper 2)	BUM2	Tualatin Hills Nature Park
Bronson Creek (Middle)	BRM1	Bronson Creek Park north of Cornell Road
Cedar Creek (Middle)	CDM2	above Meineke Road
Cedar Creek (Upper)	CDM1	below Rein Road
Cedar Mill Creek (Middle)	CMM1	above Jenkins Road on Nike campus
Chicken Creek (Lower)	CNM3	Upstream of mouth
Christensen Creek (Lower)	CHM2	above 219 bridge
Council Creek (Middle)	CLM1	Oregon Roses property above pond
Dairy Creek (Lower E Fork)	DYM3	above Roy Road
Dairy Creek (Middle W Fork)	DYM5	below highway 26
Dawson Creek (Lower)	DNM2	below Baseline Road
Dawson Creek (Upper)	DNM1	above Airport Road
Fanno Creek (Middle)	FMM1	downstream (south) of Scholls Ferry Road
Fanno Creek (Upper 2)	FUM2	OES property (upstream of Nicol Road)
Gales Creek (Lower)	GSM3	below Rt 47 in Forest Grove
Heaton Creek (Middle)	HTM1	above NE Mountain Home Road
Hedges Creek (Lower)	HDM1	in Tualatin Hills Park along Boones Ferry Road
Johnson Creek (Lower South)	JSM3	upstream of Route 8
Johnson Creek (Mid South)	JSM2	upstream of Trillium Road (N of Davis Road)
Johnson Creek (Middle North)	JNM1	1/6 mile upstream of Cedar Hills Blvd
Johnson Creek (Upper South)	JSM1	below 170th and Rigert intersection
McFee Creek (Lower)	MFM2	below SW Hillsboro Hwy (219)
McKay Creek (Lower)	MKM3	at mouth north of Baseline
McKay Creek (Middle)	MKM2	below Church Road
Rock Creek (Lower)	RLM1	below River Road
Rock Creek (Middle)	RMM1	park west of John Olsen Road (take Windstone Court)
Rock Creek (Upper 2)	RUM2	behind Rock Creek Tavern on D Silva property
Saum Creek (Lower)	SAM1	below Borland Road
Scoggins Creek (Lower)	SCM3	below Stimson Mill on Patton Valley Road
Scoggins Creek (Middle)	SCM2	below Hagg Lake on Mill Road
Summer Creek (Lower)	SMM2	1/8 mile above mouth
Summer Creek (Upper 2)	SMM1	below 1st crossing under Schools Ferry
Sylvan Creek (Middle)	SVM1	off of Scholls Ferry Road @ flow station
Willow Creek (Lower)	WLM2	in Salix Park below Heritage Parkway

Table 1. (Continued).

Stream Name	Study Reach Code	Macroinvertebrate Sampling Location
High-gradient Reaches		
Ash Creek (Upper)	ASM1	above Taylors Ferry Road
Ayers Creek (Upper)	AYM1	above 1st Road Xing along Dopp Road
Baker Creek (Upper)	BKM1	above Kruger Road
Bannister Creek (Lower)	BAM1	Above Laidlaw Rd above confluence with Bronson
Bronson Creek (Upper)	BRM1	above Saltzman
Burris Creek (Upper)	BIM2	above falls upstream of SW Stickney Road
Cedar Mill Creek (Upper)	CMM2	upstream of 113th Street
Chicken Creek (Middle)	CNM2	below Edy Road
Chicken Creek (Upper)	CNM1	above Kruger Road
Christensen Creek (Upper)	CHM1	above Dixon Mill Road (above pond)
Dairy Creek (Middle E Fork)	DYM2	1/2 mile below Meachum Road
Dairy Creek (Upper E Fork)	DYM1	Little Bend Park
Dairy Creek (Upper W Fork)	DYM4	above 1st Nehalem Highway road crossing N of 26
Fanno Creek (Lower)	FLM1	Durham City Park below bridge
Fanno Creek (Upper 1)	FUM1	below 39th Street
Gales Creek (Middle)	GSM2	at access site off of Gales Creek Road
Gales Creek (Upper)	GSM1	below Gales Creek Campground
Golf Creek (Upper)	GLM1	below Barnes Road Xing
McFee Creek (Upper)	MFM1	above Finnigan Hill Road
McKay Creek (Upper)	MKM1	below Northrup Road crossing
Roaring Creek (Middle)	RGM1	along Roaring Creek Road
Rock Creek (Upper 1)	RUM1	along Rock Creek Road
Sain Creek (Lower))	SNM1	above Henry Hagg Lake
Scoggins Creek (Upper)	SCM1	below confluence with Parsons Creek
Tanner Creek (Lower)	TNM1	above Scoggins Valley Road Xing
Willow Creek Upper)	WLM1	below 143rd Ave

gradient or high gradient. Generally, reaches with gradients exceeding 1.5% contained coarse (gravel, cobble, and boulder) substrate that allowed riffles to occur at a frequency sufficient to sample from them (>10–15% total habitat area). Glides were sampled from reaches that had gradients lower than 1.5% and no, or infrequent (<10% total habitat area), riffles, and predominantly sand and finer substrates.

Macroinvertebrates were collected using the Level 3 sampling protocols, as described in WQIW (1999). At each of the 63 study reaches, two units of the same habitat type (riffles or glides, as described above) were selected for sampling. From each of these two units, two instream sampling points were selected using a random numbers table. Two four-digit numbers were selected: the first two digits represented the percent distance upstream through the unit and the second two digits represented the percent of stream width across the unit. In reaches with only one continuous unit (most often glides in low-gradient reaches), four instream sampling points were selected from within this single habitat unit.

Macroinvertebrates were collected with a D-frame kicknet (12-in wide, 500-µm mesh opening) from a 30 x 60 cm (1 x 2 ft) area at each of these sampling points. A 1 x 2 ft metal frame with sheet-metal sides and open front and rear ends was placed over each sample point to contain the sample material and prevent organisms and debris from escaping outside the net. Larger substrates, when present, were first hand-washed inside the net, and then placed outside of the sampled area. The area was then thoroughly disturbed by hand (or by foot in deeper water) to a depth of ~5 cm. In areas with little or no discernible streamflow, the kicknet was pulled back and forth through the water column over the disturbed area to collect suspended materials.

The four samples from a reach were placed together into a 500-μm sieve and carefully washed to remove larger substrate and leaves after inspection for clinging macroinvertebrates. The composite sample was then placed into one or more 1-L polyethylene wide-mouth jars, labeled, and preserved with 70% isopropyl alcohol for later sorting and identification at the laboratory.

Following macroinvertebrate sample collection at each reach, we collected the following water chemistry data: pH, temperature, dissolved oxygen, and specific conductance. Temperature, dissolved oxygen, and conductivity were measured in the field using a YSI Model 85 water chemistry meter. We measured pH in the field with an Oakton pHTestr 3.

Pysical habitat information was collected at each reach with both visual estimate and quantitative measurement techniques (Table 2). First, valley type was determined from landscape features and was classified as a U, V, or open floodplain. At each of six evenly spaced channel cross sections, wetted width, bankfull width, bankfull and incised heights (measured with a surveyor's rod and fiberglass measuring tape), and bank angles (measured with a clinometer) were measured. Canopy cover was measured with a spherical densiometer on the left and right bank, and in four directions (upstream, downstream, left, and right) in the center of the channel cross section. Stream water depth was measured at five equally-spaced locations along each cross section (30 total depth measurements for each reach), and substrate size composition (10 categories) and embeddedness were recorded at each of 15 equally-spaced locations along each cross section (90 total substrate size tallies for each reach). Substrate composition was determined by size tallies, performed by placing a finger into the water and classifying the size of the particle first touched as bedrock (> 4000 mm), boulder (250–4000 mm), cobble (64–250 mm), coarse gravel (16–64 mm), fine gravel (2–16 mm), sand (0.06–2.00 mm), fines (<0.06 mm), wood, hardpan (firm, consolidated fines), or other. Embeddedness (%) was visually estimated from the area immediately surrounding each sampled particle.

Immediately following cross section surveys, large wood (>6 in diameter) was tallied and organic layer accumulation in depositional zones was measured. Visual estimates or classifications were then made of dominant bank material, percent stable bank, percent undercut bank, dominant erosional bed material and dominant depositional bed material, erosional habitat embeddedness (%), and depositional habitat embeddedness (%), and instream filamentous algae cover (%) and macrophyte cover (%). On each bank, the riparian zone buffer width (defined for this study as the area within which natural mature vegetative communities occurred) and the dominant adjacent land use outside the riparian buffer area were recorded. The reach also was classified using the Rosgen Level 2 stream morphology classification system (Rosgen 1996). This system classifies stream reaches based on channel slope, dominant channel materials, channel entrenchment, the width-to-depth ratio, and sinuosity. Streams were classified using this system to more precisely characterize high- and low-gradient reaches in relation to morphological features.

SAMPLE SORTING AND MACROINVERTEBRATE IDENTIFICATION

Samples were sorted to remove a 500-organism subsample from each preserved sample following the procedures described in the Level 3 protocols (WQIW 1999) and using a Caton gridded tray, as described by Caton (1991). Contents of the sample were first emptied onto the gridded tray and then floated with water to evenly distribute the sample material across the tray. Squares of material from the 30-square gridded tray were removed to a Petri dish which then was placed under a dissecting microscope at 7-10X to sort aquatic macroinvertebrates from the sample matrix. Macroinvertebrates were removed from each sample until at least 500 organisms were counted, or until the entire sample had been sorted.

Following sample sorting, all macroinvertebrates were identified to the level of taxonomic resolution recommended for Level 3 macroinvertebrate assessments (WQIW 1999). Larval Chironomidae from low-gradient reaches were identified to genus to provide further

Table 2. Environmental variables collected in the field and generated using geographical information systems (GIS) for characterizing streams in the Tualatin River basin, Oregon, fall 2001.

Variable	Quantitative or Categorical	Data Source (GIS or Field)	Visual Estimate or Measured Variable
Forest (%)	Q	G	M
Agriculture (%)	Q	G	M
Urban (%)	Q	G	M
Roads (%)	Q	G	M
Effective impervious area (EIA)	Q	G	M
Reach length	Q	F	M
Valley type	C	F	V
Channel type	C	F	M
Reach gradient (%)	Q	F	M
Wetted width	Q	F	M
Bankfull width	Q	F	M
Bankfull height	Q	F	M
Mean water depth	Q	F	M
Discharge	Q	F	M
Percent riffles	Q	F	V
Percent glides/runs	Q	F	V
Percent pools	Q	F	V
Dominant eros material	C	F	V
Dominant dep material	C	F	V
Substrate composition	Q	F	M
Percent embeddedness	Q	F	M
Large wood tally	Q	F	M
Organic layer accumulation	Q	F	V
% Filamentous algae cover	Q	F	V
% Macrophyte cover	Q	F	V
Overhead canopy cover	Q	F	M
Dominant bank material	C	F	V
% Stable bank	Q	F	V
% Undercut bank	Q	F	V
Mean riparian buffer width	Q	F	V
% Tree cover in riparian zone	Q	F	V
% Nonnative riparian veg cover	Q	F	V
Dom adjacent land use	C	F	V
Water temperature (°C)	Q	F	M
pH	Q	F	M
Specific conductance (µS/cm)	Q	F	M
Dissolved oxygen (mg/L)	Q	F	M

characterization of aquatic macroinvertebrate communities in those reaches. Aquatic insects were keyed using Merritt and Cummins (1996) and a number of regional and taxa-specific keys. Chironomidae were identified to genus using Weiderholm (1983). Other invertebrates were keyed using Pennak (1989).

QUALITY ASSURANCE

Following Level 3 protocols (WQIW 1999), we collected duplicate composite samples at 10% of the sampled reaches in the field (six samples). Duplicate samples were compared to assess within-site sample variability. Additionally, a voucher collection of all macroinvertebrate taxa identified in the study was assembled as a standard reference for the project identification work.

DATA ANALYSIS

Data were analyzed using multimetric and multivariate techniques. Data were entered into Excel spreadsheets and formatted as needed for each analysis. Multivariate analyses were performed using PC-Ord Version 4 statistical software. All other statistical analyses were performed with SPSS Version 10.0. For all multivariate analyses, macroinvertebrate density data were log (x+1) transformed to reduce the influence of very large values (Krebs 1989). This type of transformation is useful when there is a high degree of variation within attributes (taxa, in the case of this study) or among attributes within a sample (McCune and Mefford 1999) and has previously been used on macroinvertebrate community data prior to performing multivariate analysis (e.g. Reece and Richardson 2000, Zimmer et al. 2000, Jackson 1993). These logarithmic density data served as the raw data for all subsequent multivariate analyses in this study.

Because no consensus exists regarding what, if any, data standardization should be performed prior to conducting multivariate analysis of community data (Jackson 1993), data were analyzed using 1) unstandardized data (e.g. Reece and Richardson 2000), 2) relative abundance (standardized in relation to row totals; e.g. Ford and Rose 2000) and, 3) data standardized relative to the taxon maximum abundance (standardized in relation to column maximum; e.g. Jackson 1993). Results of multivariate analyses using these three types of data were generally similar; however, ordination of relative abundance data produced the strongest correlations with environmental variables and tested metrics, so these results were used for examining conditions of low-gradient reach communities and are presented in this study.

Land use data for each reach were calculated in Arc/Info from 1990 land use/land cover data produced by the Pacific Northwest Ecosystem Research Consortium. Anderson level II classifications were reclassified to provide measures of percent urban, agriculture, forested, and road land uses. The percent coverage of each land use type was calculated in a 2000-m long by 800-m wide (400-m from each bank) buffer upstream of each sample reach.

PATTERN ANALYSIS OF ALL MACROINVERTEBRATE DATA

To confirm that the sampling design had produced two relatively distinct macroinvertebrate community data sets that reflected high- and low-gradient reach types, and to perform an overall pattern analysis on the entire data set, all reaches were first compared to one another using multivariate techniques. First, cluster analysis was performed to arrange reaches in a hierarchical classification using the Sorenson (Bray-Curtis) distance measure, and flexible unweighted pair-group arithmetic averaging (flexible UPGMA) (Gauch 1982, Krebs 1989, Marchant, et al. 1999). Non-metric multidimensional scaling (NMS) was then performed using the Sorenson (Bray-Curtis) distance measure and a minimum of 400 iterations. NMS, a non-parametric ordination technique, was selected as the ordination procedure because it is robust to data departures from normality, assumes no underlying distribution of the data, and for these reasons is suggested to be particularly suitable for use with ecological data (McCune and Mefford 1999). These two approaches to pattern analysis are considered to be complementary to one another, as classification first helps identify groups of reaches that have the most similar taxa composition, then ordination further elucidates these patterns by ordinating the reaches in relation to one another in *k*-dimensional space (Gauch 1982).

To determine whether the differences in community types were a result of sampling from different habitat types in high- and low-gradient reaches, or a result of overall environmental differences between reach types, total taxa richness and total mayfly, stonefly, and caddisfly taxa richness (EPT richness) were compared between years from reaches that were sampled both years. Because glides were sampled from high-gradient reaches in 2000, we were able to compare 2001 riffle to 2000 glide samples from reaches sampled in both years to determine what effect sampling different habitat types within a single stream type had on the resulting macroinvertebrate data. If differences in taxa richness and composition between 2000 and 2001 high-gradient samples were small, then differences between low-gradient and high-gradient reaches would primarily from differences in overall stream type and condition, and not a result of sampling from two different habitat types.

CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS IN HIGH- AND LOW-GRADIENT REACHES

Physical and chemical properties were summarized and compared between high- and low-gradient reaches to further examine how these two stream types differ in the basin. To better explore relationships between physical and biological conditions, several classes of variables such as percent urban, percent agriculture, and percent road land uses; percent coarse gravel, cobble, and boulder; and percent sand and fine substrate were summed to produce variables named “percent urban, roads, and ag”, “percent coarse substrate”, and “percent sand and fines”.

ANALYSIS OF LOW-GRADIENT REACH MACROINVERTEBRATE DATA

Macroinvertebrate community data from low-gradient reaches were analyzed using multivariate pattern analysis and indirect gradient analysis, as well as by analysis with a set of selected community metrics. Currently, there are no widely-accepted analytical tools to evaluate macroinvertebrate communities in low-gradient stream reaches on the Tualatin Valley floor. The first step towards developing such tools is to examine relationships between macroinvertebrate community structure and environmental conditions, including water quality, physical habitat conditions, and surrounding land use. Although reference conditions for low-gradient, valley floor streams may no longer exist, a range in land use intensity and types may produce enough variation in local stream environmental conditions to result in measurable differences in macroinvertebrate community structure that could be related to these environmental gradients. To examine low-gradient reaches for patterns in community composition, cluster analysis was performed on the data using the Sorenson (Bray-Curtis) association measure and flexible UPGMA. NMS was then performed using the Sorenson association measure and a minimum of 400 iterations to ordinate reaches based on community similarities and to allow subsequent correlation of ordinations with environmental variables (indirect gradient analysis).

Environmental variables to be correlated with macroinvertebrate NMS ordinations were first checked for normality using normal probability plots. Data were then log and square-root transformed where necessary. Environmental variables were then correlated with the resulting ordinations axes to examine whether major gradients in community structure were correlated with measured chemical, physical, or landscape attributes. The endpoints of this type of analysis are the identification 1) of groups of reaches and major gradients of site similarity, and 2) the identification of environmental variables that are correlated with major gradients in community similarity.

To identify the taxa responsible for major the gradients in community structure, correlations were computed between the NMS ordinations and the macroinvertebrate data matrix. The resulting information can be used to examine what taxa or taxa groups might be appropriate indicators of biological conditions in low-gradient reaches of the Tualatin Valley floor, based on patterns of abundance in relation to major patterns in overall site similarity.

A similar approach was used to identify community metrics most closely correlated with major gradients in community structure. Metrics that provided a range of values among low-gradient reaches were selected for inclusion in the set; metrics that showed little variation among low-gradient reaches, such as sensitive taxa richness, were excluded from the set. Metrics were calculated for each sample; then the set was correlated with NMS ordination axes to determine how well the major gradients in community composition produced by NMS corresponded to the selected metrics known to be responsive to degradation. As a final measure of macroinvertebrate community conditions in low-gradient reaches, each sample reach was ranked in relation to other reaches for each metric score. A mean rank was then computed for each reach to provide a measure of relative benthic community condition.

ANALYSIS OF HIGH-GRADIENT REACH MACROINVERTEBRATE DATA

High-gradient reach data were analyzed using multimetric analysis. Multimetric analysis employs a set of community metrics, each of which describes an attribute of the macroinvertebrate community that is known to be responsive to one or more types of pollution or habitat degradation. This approach uses scoring criteria that convert raw metric values to standardized scores that can be summed to produce a single numeric measure of overall biological integrity. Reference condition data are required to develop this type of assessment tool. Metric sets and standardized metric scoring criteria are developed and calibrated for specific community types, based on both geographic location and stream/habitat type. The Oregon Department of Environmental Quality (DEQ) currently employs a 10-metric set for use with riffle samples from higher gradient streams in western Oregon (WQIW 1999).

This metric set was used in this analysis and tested for its ability to reflect the condition of high-gradient reaches of the Tualatin River basin in relation to environmental conditions. This metric set includes six positive metrics, which score higher in less disturbed systems and four negative metrics, which score lower as conditions improve (Table 3). The Modified Hilsenhoff Biotic Index (HBI), originally developed by Hilsenhoff (1982), computes an index to organic enrichment pollution based on the relative abundance of various taxa at a site. Values of the index range from 1 to 10; higher scores are interpreted as an indication of a degraded (i.e., pollution tolerant) macroinvertebrate community. Sensitive taxa are those that are intolerant of warm water temperatures, high sediment loads, and organic enrichment; tolerant taxa are adapted to persist under such adverse conditions. We used DEQ's taxa attribute coding system to assign these classifications to taxa in the data set (DEQ, unpublished information).

Metric values were first calculated for each sample, then were converted to standardized scores

Table 3. Metric set and scoring criteria (WQIW 1999) used to assess condition of macroinvertebrate communities in the Tualatin River basin, Oregon, fall 2001.

	Scoring Criteria		
Metric	5	3	1
POSITIVE METRICS			
Taxa richness	>35	19–35	<19
Mayfly richness	>8	4–8	<4
Stonefly richness	>5	3–5	<3
Caddisfly richness	>8	4–8	<4
Number sensitive taxa	>4	2–4	<2
# Sediment sensitive taxa	≥2	1	0
NEGATIVE METRICS			
Modified HBI[1]	<4.0	4.0–5.0	>5.0
% Tolerant taxa	<15	15–45	>45
% Sediment tolerant taxa	<10	10–25	>25
% Dominant	<20	20–40	>40

[1] Modified HBI = Modified Hilsenhoff Biotic Index

using DEQ scoring criteria for riffle samples from western Oregon streams (Table 3). The standardized scores were summed to produce a multimetric score ranging between 10 and 50. Reaches were then assigned to a level of impairment based on these total scores (Table 4).

Finally, relationships between multimetric scores and selected environmental variables were examined using nonparametric correlation analysis (Spearman's Rho) to determine how well the metric set responds to increasing levels of disturbance in the Tualatin River basin.

COMPARISON OF YEAR 2000 AND 2001 RESULTS

Year 2000 data were compared to year 2001 macroinvertebrate data using only low-gradient data because high-gradient samples were collected from different habitat types in the two sampling years. Low-gradient data were examined to determine the similarity 2000 and 2001 site conditions. If differences occurred, the data sets would then be further examined to determine whether sampling error, or real changes in community composition were producing these differences. Three metrics: total taxa richness, total EPT richness, and the modified HBI were compared between years. When 2000 and 2001 metrics were paired up by site, it was apparent that unidirectional differences indicative of more impaired community conditions had occurred between years in many of the reaches. To examine whether significant differences were occurring in these community attributes between 2000 and 2001, paired t-tests were performed on untransformed HBI and richness data following examination of data for normality with normal probability plots and Kolmogorov-Smirnov tests of normality.

Table 4. Multimetric score ranges for assignment of macroinvertebrate community condition levels (WQIW 1999).

Level of Impairment	Score Range (scale of 10–50)
None	>39
Slight	30–39
Moderate	20–29
Severe	<20

RESULTS

PATTERN ANALYSIS OF ALL MACROINVERTEBRATE DATA

Cluster analysis of all 63 samples produced 2 groups of reaches at the farthest dissimilarity distance (Figure 2). With the exception of a small group of high-gradient reaches with impaired macroinvertebrate communities on the right side of the left cluster, these two groups represent high-gradient reach samples on the right and low-gradient reach samples on the left, indicating that the sampling design produced two distinct types of community information with few exceptions: one type from high-gradient riffles, and the other from low-gradient glides. Ordinations of reaches resulting from NMS also showed clear separation on two dimensions between most samples from low-gradient and high-gradient reaches (Figure 3). The only exception to this grouping was the occurrence of a number high-gradient reach samples from urbanized areas with heavily impaired communities; these samples much more closely resembled low-gradient samples than other high-gradient samples.

A number of environmental variables, including percent fine substrate, percent sand and fine substrate, embeddedness, percent coarse substrate, reach gradient, percent riffles, percent urban land use, EIA, percent urban and agricultural land use, and percent forestry land use, were highly correlated ($p < 0.001$) with NMS axes one and two; these variables, some indirectly, are likely producing these major patterns in community composition observed in the basin.

Mean taxa richness and mean EPT richness from high-gradient glide samples in 2000 were 26.3 and 10.4, respectively, as compared to 26.3 and 12.9 from high-gradient riffle samples in 2001 (Figure 4). In contrast, low-gradient glide samples had much lower mean taxa and EPT richness than those from high-gradient samples in both 2000 and 2001 (Figure 4), indicating that these groups produced by the multivariate analyses are resulting primarily from the differences between high- and low-gradient stream reaches in their overall capacity to support diverse, sensitive macroinvertebrate communities, and not a result of sampling from different habitats.

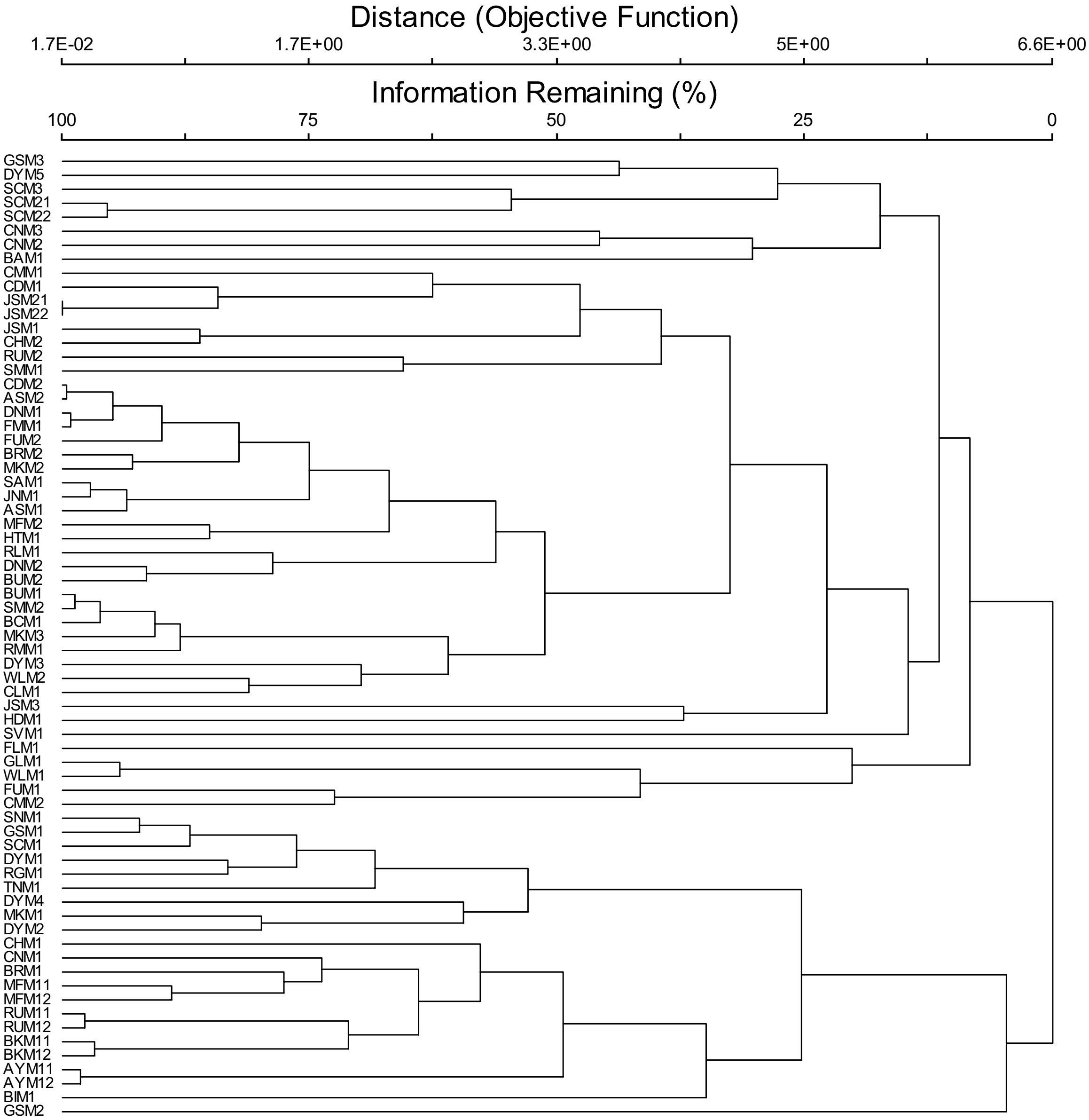

Figure 2. Dendrogram of cluster analysis of Curtis-Bray association measures of macroinvertebrate communities sampled from 63 sample reaches in the Tualatin River basin, Oregon, fall 2001.

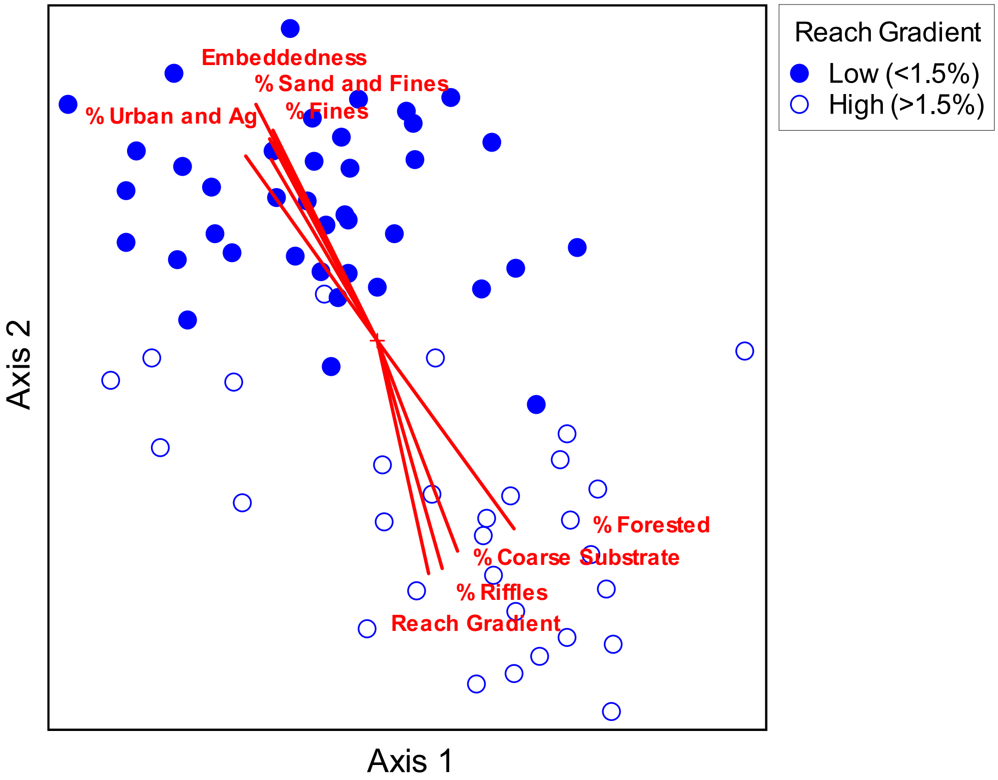

Figure 3. MS ordination biplot of macroinvertebrate samples collected from high- and low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Only environmental variables with most significant correlation coefficients ($p < 0.001$, r cutoff = 0.600) are included on the biplot. Vector lines of environmental variable overlays point in the direction that the stated variable increases; longer lines indicate stronger correlation with one or both axes.

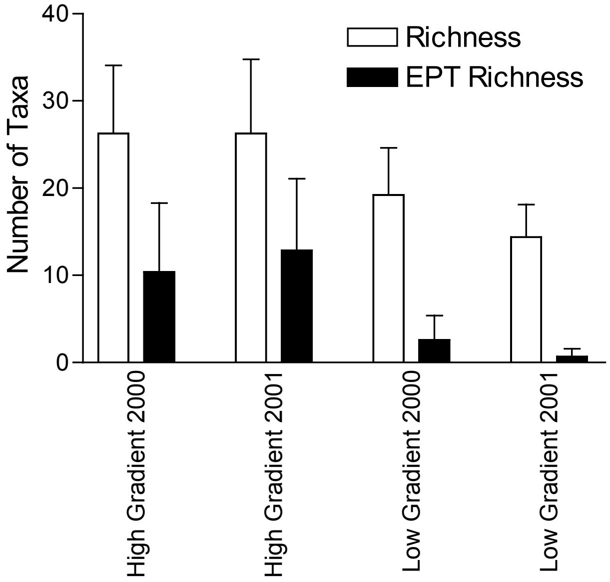

Figure 4. Mean taxa richness and richness of mayflies, stoneflies and caddisflies (EPT) in high- and low-gradient stream reaches sampled in the Tualatin River basin, Oregon, fall 2000 and fall 2001.

CHARACTERIZATION OF ENVIRONMENTAL CONDITIONS IN HIGH AND LOW-GRADIENT REACHES

Streams sampled in this study encompassed a wide range of land use conditions, riparian and bank conditions, stream channel dimensions, gradients, and substrate characteristics (Table 5). Based on the Rosgen stream classification system, higher gradient reaches were channel types A, B, or C and substrate types 3 or 4, characterized by gradients >1.5–2% and dominant substrates of coarse gravel or cobble. These reaches were generally dominated by riffle-pool complex habitat, and were usually contained within U or V-shaped valleys in areas of more topographic relief along the periphery of the Coast, Tualatin, and Chehalem Mountain Ranges. Riparian zone conditions ranged from completely intact mature forest in forested areas to non-existent buffers and maintained lawns and parks up against the top of the bank slope.

Low-gradient reaches fell into the E6 and F6 Rosgen level II stream classes, characterized by gradients usually <1.5% and dominant substrates of sand and silt. Glide and pool habitat comprised most, if not all, aquatic habitat in these low-gradient reaches; riffles were infrequent, if not absent. Riparian zone conditions ranged widely, but tended to be poorer (as determined by buffer width, % non-native vegetation, and % tree cover)

Table 5. Environmental conditions (mean [range]) of low-gradient and high-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001.

	Reach Type Mean (Range)	
Environmental Variable	Low-gradient	High-gradient
Urban (%)	38.7 (0.0–75.0)	14.9 (0.0–0.80)
Agriculture (%)	32.8 (2.0–94.0)	27.4 (0.0–71.0)
Urban, Agri., Roads (%)	83.7 (37.0–99.0)	47.0 (0.0–99.0)
Forest (%)	15.4 (1.0–60.0)	53.2 (20.0–100.0)
Effective impervious area (%)	26.5 (0.0–51.50)	10.0 (0.0–51.8)
Reach gradient (%)	1.0 (0.5–1.5)	3.2 (1.5–5.5)
Wetted width (m)	4.2 (0.3–10.1)	3.3 (0.9–9.5)
Bankfull width (m)	5.6 (0.5–11.8)	5.7 (1.5–17.1)
Mean water depth (cm)	24.4 (4.2–67.5)	8.5 (1.9–19.1)
Percent riffles	3.2 (0.0–10.0)	49.6 (15.0–80.0)
Percent glides/runs	52.7 (0.0–90.0)	27.2 (0.0–75.0)
Percent pools	44.0 (10.0 -100.0)	23.2 (0.0–50.0)
Percent coarse substrate	8.1 (0.0–40.0)	53.0 (2.2–87.8)
Percent sand and fines	67.1 (13.3–100.0)	20.9 (2.2–78.8)
Percent fines	60.0 (1.1–100.0)	12.3 (0.0–78.8)
Percent hardpan	9.7 (0.0–78.9)	1.0 (0.0–6.7)
Embeddedness (%)	89.3 (55.9–100.0)	45.6 (12.0–92.0)
Large wood tally	11.9 (0–50)	8.9 (0–25)
Filamentous algae (%)	5.3 (0–60)	0.3 (0–10)
Macrophytes (%)	14.0 (0–80)	0.8 (0–25)
Canopy cover (%)	64.3 (1.0–97.9)	90.8 (48.9–100.0)
Bank stability (%)	58.2 (10–95)	75.8 (10–100)
Mean riparian buffer width (m)	23.7 (2.2–91.5)	74.0 (1.5–150+)
Tree cover in riparian zone (%)	36.7 (0 - 80)	68.9 (5–90)
Rip nonnative veg cover (%)	42.3 (0 -100)	17.6 (0–65)
Water temperature (^{o}C)	16.3 (11.1–21.4)	13.6 (10 -20)
Spec. conductance (µS/cm)	198.4 (78.6–621.0)	128.8 (49.0–252.4)
Dissolved oxygen (% sat)	58.9 (6.0–101.0)	86.1 (50.8–105.1)

than in high-gradient reaches, which generally occur on the periphery of, and beyond agricultural and urban areas. Importantly, agricultural and urban land uses are higher in low-gradient reaches (mean = 84%, range = 37 to 99%) than in high-gradient reaches (mean = 47%, range 0 to 97%), as would be expected, which further illustrates the lack of sufficient reference reaches for valley floor reaches. Low-gradient reaches also tended to have more impaired water quality with lower dissolved oxygen concentrations and higher conductivities than did high-gradient reaches.

ANALYSIS OF LOW-GRADIENT REACH MACROINVERTEBRATE DATA

Low-gradient reaches generally exhibited low taxa richness, few or no EPT taxa, high dominance by only a few taxa, and high community-wide tolerance to extreme environmental conditions, as measured by the modified HBI (Table 6).

Hierarchical cluster analysis of low-gradient reach data produced a dendrogram that didn't show any distinct groups, or clusters, of reaches. NMS produced a 3-dimensional ordination that explained 76% of the original variation among samples. Axis 3 accounted for half of that explained variation (unlike other ordination procedures, NMS does not number axes to explain successively smaller amounts of variation). The only environmental variables significantly correlated with ordination axis 1 were wetted and bankfull widths (r = -0.541, p < 0.001 and r = -0.525, p < 0.001, respectively). Percent urban land use, percent agricultural land use, dissolved oxygen, and EIA were all significantly correlated with axis 2 (Table 7, Figure 5), and measures of substrate composition, including embeddedness, percent fines, and percent sand and fines had highly significant correlations with axis 3. These correlations with environmental variables indicate that recognizable patterns in community structure occur in the basin in relation to stream size, urban land use intensity, instream substrate composition, and low dissolved oxygen concentrations.

Taxa that showed the strongest correlation with ordination axis 3 included Acari (r = 0.499), *Optioservus* (r = 0.548), *Chironomus* (r = -0.419), *Parametriocnemus* (r = 0.449), *Procladius* (r = -0.531), *Chelifera* (r = 0.453), *Baetis tricaudatus* (r = 0.416), Corixidae (r = -0.591), *Sialis* (r = -0.678), Hydrobiidae (r = 0.488), *Juga* (r = 0.410), and Sphaeriidae (r = -0.499). Taxa with negative correlation coefficients tended to increased in abundance, and those with positive correlation coefficients decreased, with decreasing substrate conditions, as determined from correlations of substrate conditions with NMS axis 3. Those taxa that tended to increase in abundance with increased physical impairment, as indicated by substrate conditions, scored an average modified HBI of 7.8, while those decreasing in abundance scored an average modified HBI of only 5.4. No EPT taxa

Table 6. Descriptive statistics and coefficients of correlation (r) with NMS axes of macroinvertebrate community attributes and overall ranks from low-gradient stream reaches sampled in the Tualatin River basin, Oregon, fall 2001.

				Correlation with NMS	
Metric	Mean (SD)	Min	Max	Axis 2	Axis 3
Taxa richness	15.0 (4.3)	8	25	0.184	0.517**
EPT richness	0.9 (1.4)	0	7	0.495*	0.615**
% Chironomidae	24.7 (21.7)	0.6	83.6	0.545**	-0.074
% Oligochaeta	13.5 (10.3)	0.0	38.2	-0.216	-0.187
% Molluska	47.8 (24.0)	7.5	94.2	-0.427*	0.104
% Dominant	43.3 (13.6)	20.0	77.0	-0.135	-0.220
% Tolerant	81.6 (15.3)	41.0	98.0	-0.444*	-0.529**
% Sediment tolerant	60.5 (21.8)	8.0	93.0	-0.495*	0.036
Modified HBI	6.8 (0.9)	5.0	9.3	-0.071	-0.708**
Overall rank	12.6 (4.25)	4.9	21.5	-0.435*	-0.499*

* p < 0.01, ** p < 0.001

Table 7. Correlation coefficients (r) of environmental variables with axes 2 and 3 of NMS ordination of Bray-Curtis similarity scores of macroinvertebrate communities from 37 low-gradient streams in the Tualatin River basin, Oregon, fall 2001. Some variables were square root (sqrt) or log (log) transformed to better approximate normality prior to performing correlation analysis.

	Correlation with NMS axes	
Environmental Variable	Axis 2	Axis 3
Forest % (sqrt)	0.254	-0.002
Agriculture % (sqrt)	0.617**	0.203
Urban %	-0.694**	-0.187
Effective impervious area	-0.619**	-0.196
Reach length	-0.023	0.176
Wetted width (log)	0.233	0.038
Bankfull width (log)	0.143	0.096
Bankfull height	0.288	0.380
Mean water depth	0.178	0.100
Percent riffles	-0.038	0.085
Percent glides/runs	-0.307	-0.234
Percent pools	0.294	0.205
Percent embeddedness	-0.178	-0.578**
Percent sand and fines	-0.260	-0.528**
Percent fines	-0.324	-0.603**
Percent woody substrate (log)	0.257	0.177
Percent hardpan (log)	0.105	0.391
Large wood tally (sqrt)	0.012	0.232
% Filamentous algae cover	-0.350	-0.192
% Macrophyte cover	-0.577**	-0.228
Overhead canopy cover	0.340	-0.032
% Stable bank	-0.195	-0.016
% Undercut bank	0.135	0.190
Mean riparian buffer width (log)	-0.107	-0.320
% Tree cover in riparian zone	0.358	-0.146
% Nonnative riparian veg cover	-0.238	0.164
Water temperature (^{o}C) (log)	-0.308	0.088
Specific conductance (µS/cm)	-0.326	-0.293
Dissolved oxygen (mg/L)	0.399	0.374

* $p < 0.01$, ** $p < 0.001$

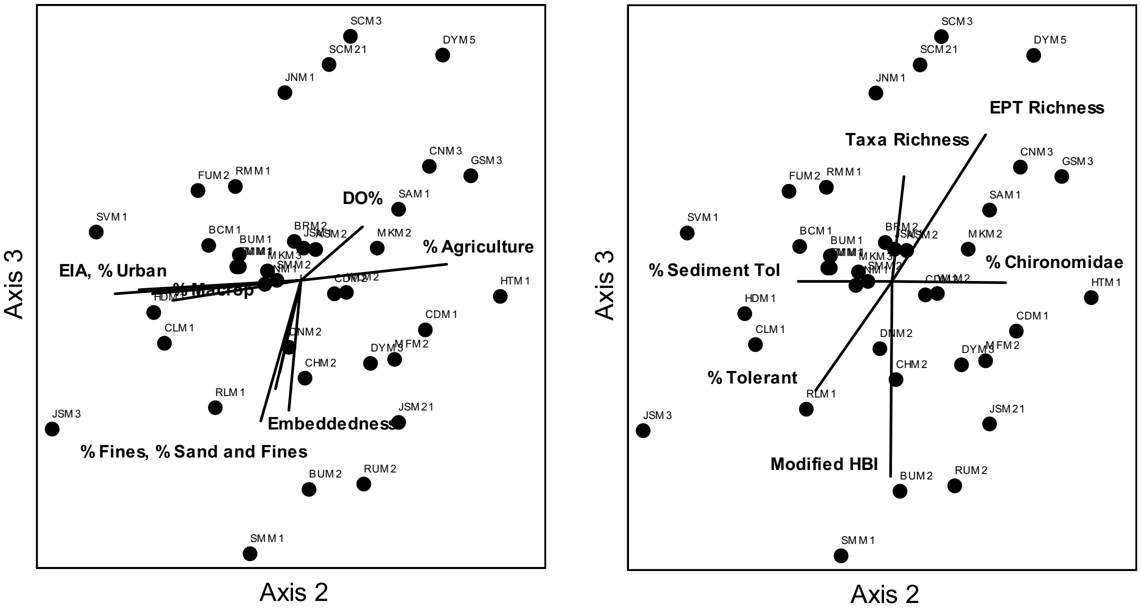

Figure 5. NMS ordination biplots of macroinvertebrate samples collected from low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Plot one includes overlays of environmental variables with highly significant ($p < 0.01$) correlation coefficients; plot two includes overlays of benthic community metrics with highly significant ($P < 0.01$) correlation coefficients. Vector lines of environmental variable overlays point in the direction that the stated variable increases; longer lines indicate stronger correlation with one or both axes.

other than *B. Tricaudatus* showed correlations higher than $r^2 = 0.150$, largely because so few EPT taxa were collected from low-gradient reaches this year. Nonetheless, EPT taxa tended to occur only in samples aggregated in the lower left corner of the NMS ordination plot of axes one and two.

Several metrics calculated from low-gradient data showed highly significant correlations with NMS axes two and three, indicating that gradients in these measured community attributes corresponded well with the community variation explained by the NMS ordination (Table 6, Figure 5), and that the variation explained by the NMS axes corresponds with gradients in community condition measured by these metrics. Overall community ranks were also highly correlated with both ordination axes two and three ($p < 0.01$).

Although EPT and other more sensitive taxa were largely absent from low-gradient samples this year, NMS still produced an ordination of reaches on axes 2 and 3 that tended to decrease in condition from the upper right to lower left quadrants of the NMS plot, as indicated by correlations with both a number of environmental variables, including percent urban land use, EIA, and percent fine substrate, as well as a with a number of benthic metrics. Overlay of EIA classes on the low-gradient NMS plot shows a trend in community structure in relation to this indicator of land use intensity (Figure 6).

To further compare conditions among low-gradient reaches, reaches were assigned ranks for each metric score, then ranks were averaged to produce a single measure of relative condition in each low-gradient reach (Table 8). Reaches ranking highest were generally located in more rural areas (with a few notable exceptions, including reach RUM2), including lower Scoggins Creek, middle McKay Creek, the middle West Fork of Dairy Creek, Heaton Creek, and lower Gales Creek. Communities in these and other higher-ranking reaches, on average, had higher richness, lower collective tolerance, and higher EPT richness than other low-gradient reaches. The lowest scoring low-gradient reaches included reaches located in Fanno, Rock, and Summer Creeks, all of which had low dissolved oxygen concentrations, which could be limiting macroinvertebrate communities in these systems.

Table 8. Mean ranks of metric scores of macroinvertebrate communities from 37 low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Reaches in bold are those showing the best macroinvertebrate community conditions among sampled reaches, as indicated by both ranks and location on NMS ordination plot.

Reach Name	Reach Code	2001 Rank
Scoggins Creek (Lower)	SCM3	4.8
Chicken Creek (Lower)	CNM3	5.3
Mckay Creek (Middle)	MKM2	5.3
Dairy Creek (Middle W)	DYM5	6.7
Johnson Ck. (Middle N)	JNM1	7.0
Gales Creek (Lower)	GSM3	7.5
Heaton Creek (Middle)	HTM1	7.5
Bronson Creek (Middle)	BRM2	8.0
Saum Creek (Lower)	SAM1	9.2
Johnson Ck. (Middle S)	JSM2	10.2
Cedar Creek (Upper)	CDM1	10.3
Council Creek (Middle)	CLM1	10.3
Scoggins Creek (Middle)	SCM2	10.8
Johnson South (Upper S)	JSM1	11.3
Mckay Creek (Lower)	MKM3	11.5
Beaverton Ck. (Upper 1)	BUM1	11.8
Rock Creek (Lower)	RLM1	12.2
Beaverton Ck. (Upper 2)	BUM2	12.5
Hedges Creek (Lower)	HDM1	12.7
Johnson Creek (Lower S)	JSM3	12.8
Beaverton Creek (Lower)	BCM1	13.0
Ash Creek (Lower)	ASM2	13.3
Cedar Mill Creek (Middle)	CMM1	13.3
Cedar Creek (Middle)	CDM2	14.2
McFee Creek (Middle)	MFM2	14.5
Christensen Ck. (Lower)	CHM2	15.0
Willow Creek (Lower)	WLM2	15.2
Dawson Creek (Lower)	DNM2	15.3
Dawson Creek (Upper)	DNM1	15.8
Fanno Creek (Upper 2)	FUM2	16.7
Summer Creek (Lower)	SMM2	16.7
Dairy Creek (Lower E)	DYM3	16.8
Rock Creek (Milddle)	RMM1	17.2
Fanno Creek (Middle)	FMM1	18.2
Sylvan Creek (Middle)	SVM1	18.8
Summer Creek (Upper)	SMM1	20.0
Rock Creek (Upper 2)	RUM2	21.5

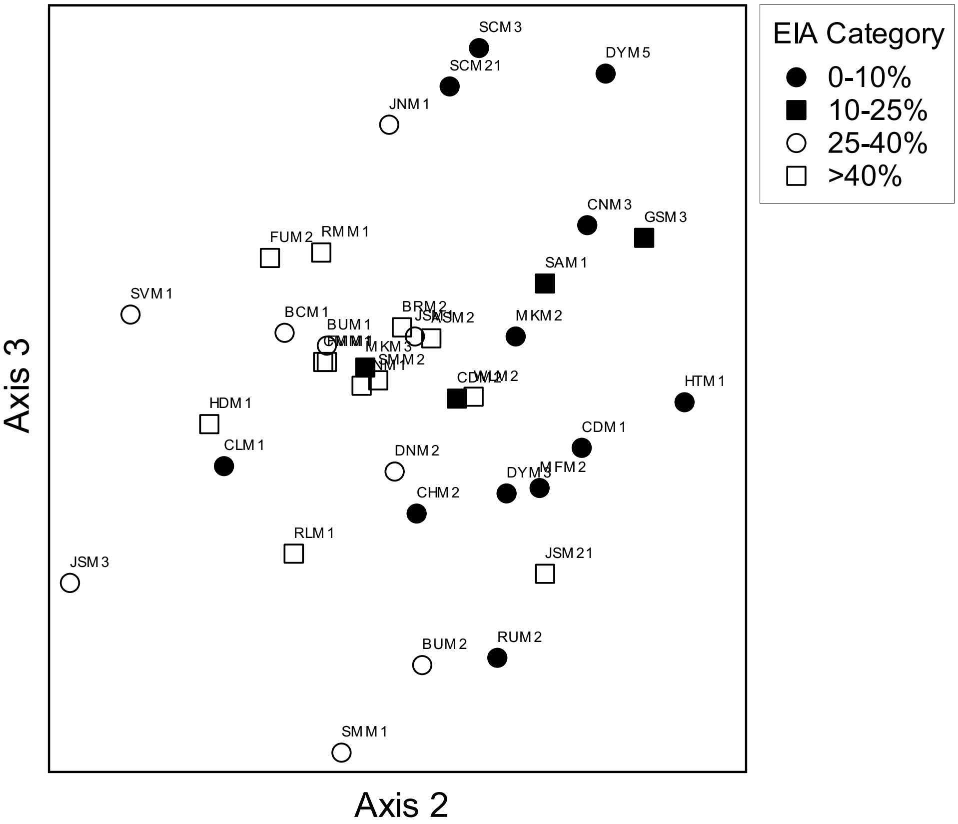

Figure 6. Overlay of effective impervious area (EIA) classes on NMS plot of macroinvertebrate communities sampled from 37 low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001.

ANALYSIS OF HIGH-GRADIENT REACH MACROINVERTEBRATE DATA

Multimetric scores of high-gradient riffle samples ranged from 14 to 38 (Table 9). Reaches scoring in the upper end of the "slight impairment" score range included upper Burris Creek, upper East and West Forks of Dairy Creek, upper Gales Creek, and Roaring Creek. These stream reaches represent the best available reference conditions for high-gradient, riffle-pool complex streams in the Tualatin River basin and are characterized as occurring in well forested drainages, and having substrate relatively free of fine sediment, and high water quality (Figures 7, 8, and 9). These reaches support species-rich communities with high EPT richness, and a collective sensitivity to habitat and water quality impairment. Chicken Creek and Christensen Creek scored only slightly lower than these first five reaches, and upper Bronson Creek, upper Baker Creek, and East Fork Dairy Creek below Meachum road scored in the lower end of the slight impairment category. These systems have lost some capacity to support the diverse assemblages that the upper Gales, Dairy, Roaring, and Burris Creek support, but still harbor EPT and other taxa that are relatively sensitive to physical and chemical impairment.

Upper Ash Creek, lower Bannister Creek, upper Fanno Creek, upper Willow Creek, upper Golf Creek, and upper Ayers Creek all scored in the severely impaired range. These stream reaches scoring in the highly impaired range primarily occurred in areas with higher urban and agricultural land use intensities, and had higher fine sediment levels, lower dissolved oxygen concentrations, and higher water temperatures.

Multimetric scores from high-gradient reaches were significantly correlated with a number of environmental variables (Table 10), indicating that the metric set employed accurately characterized macroinvertebrate community conditions in relation to these measures of instream and land use

Table 9. Multimetric scores of macroinvertebrate communities sampled from 26 high-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001.

Reach Name	Reach Code	2001 Multimetric Score
SLIGHTLY IMPAIRED		
Dairy Creek (Middle East Fork)	DYM1	38
Dairy Creek (Upper West Fork)	DYM4	38
Gales Creek (Upper)	GSM1	38
Burris Creek (Upper)	BIM1	36
Roaring Creek (Middle)	RGM1	36
Christensen Creek (Upper)	CHM1	34
Chicken Creek (Upper)	CNM1	34
Bronson Creek (Upper)	BRM1	32
Dairy Creek (Upper East Fork)	DYM2	32
Scoggins Creek (Upper)	SCM1	32
Sain Creek (Lower)	SNM1	32
Baker Creek (Upper)	BKM1 (Duplicate 1)	30
Baker Creek (Upper)	BKM1 (Duplicate 2)	30
McFee Creek (Upper)	MFM1 (Duplicate 1)	30
McFee Creek (Upper)	MFM1 (Duplicate 2)	28
MODERATELY IMPAIRED		
Rock Creek (Upper 1)	RUM1 (Duplicate 1)	28
Tanner Creek (Lower)	TNM1	28
McKay Creek (Upper)	MKM1	26
Fanno Creek (Lower)	FLM1	24
Rock Creek (Upper 1)	RUM1 (Duplicate 2)	24
Cedar Mill Creek (Upper)	CMM2	22
Chicken Creek (Middle)	CNM2	20
Gales Creek (Middle)	GSM2	20
SEVERELY IMPAIRED		
Ash Creek (Upper)	ASM1	18
Bannister Creek (Lower)	BAM1	18
Fanno Creek (Upper 1)	FUM1	18
Willow Creek Upper)	WLM1	18
Golf Creek (Upper)	GLM1	16
Ayers Creek (Upper)	AYM1 (Duplicate 2)	16
Ayers Creek (Upper)	AYM1 (Duplicate 1)	14

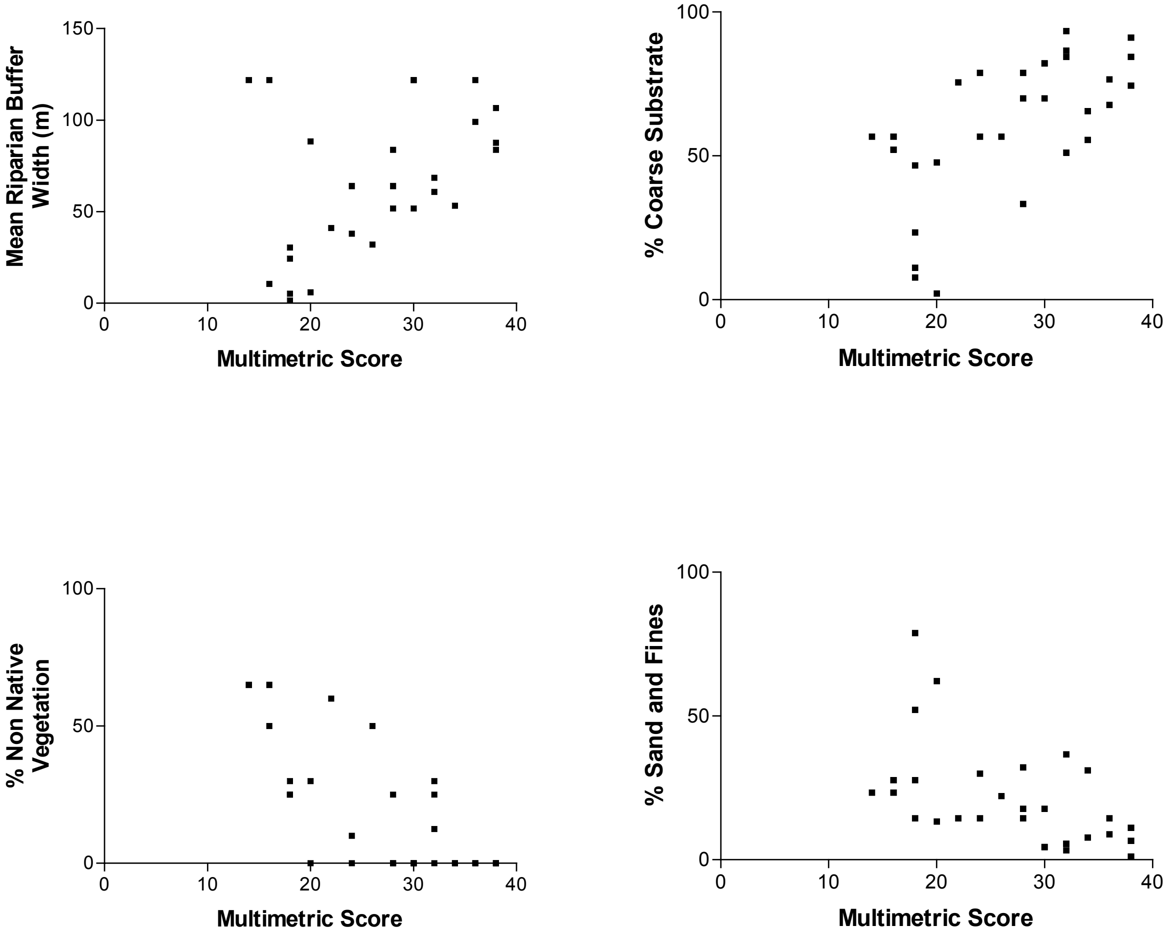

Figure 7 Relationship between macroinvertebrate community multimetric scores and physical habitat variables found to be significantly correlated with these scores from high-gradient stream reaches sampled in the Tualatin River basin, Oregon, fall 2001.

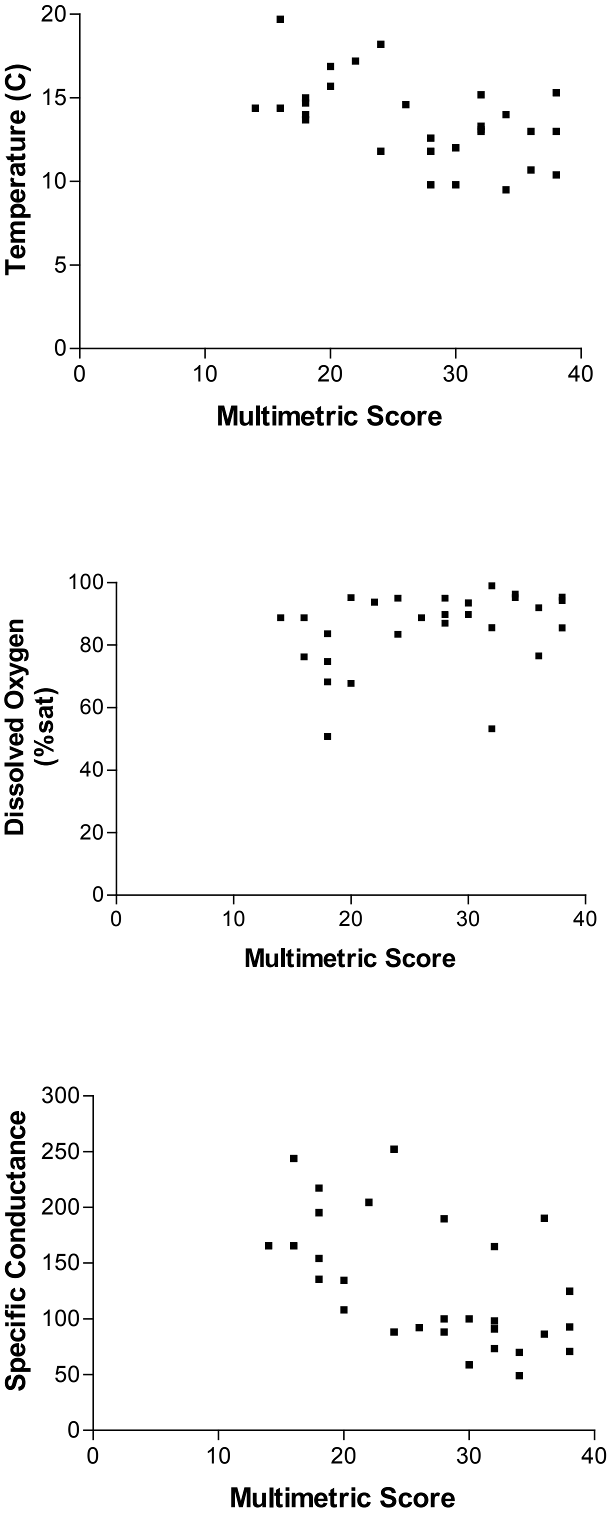

Figure 8. Relationship between macroinvertebrate community multimetric scores and water quality variables found to be significantly correlated with these scores from high-gradient stream reaches sampled in the Tualatin River basin, Oregon, fall 2001.

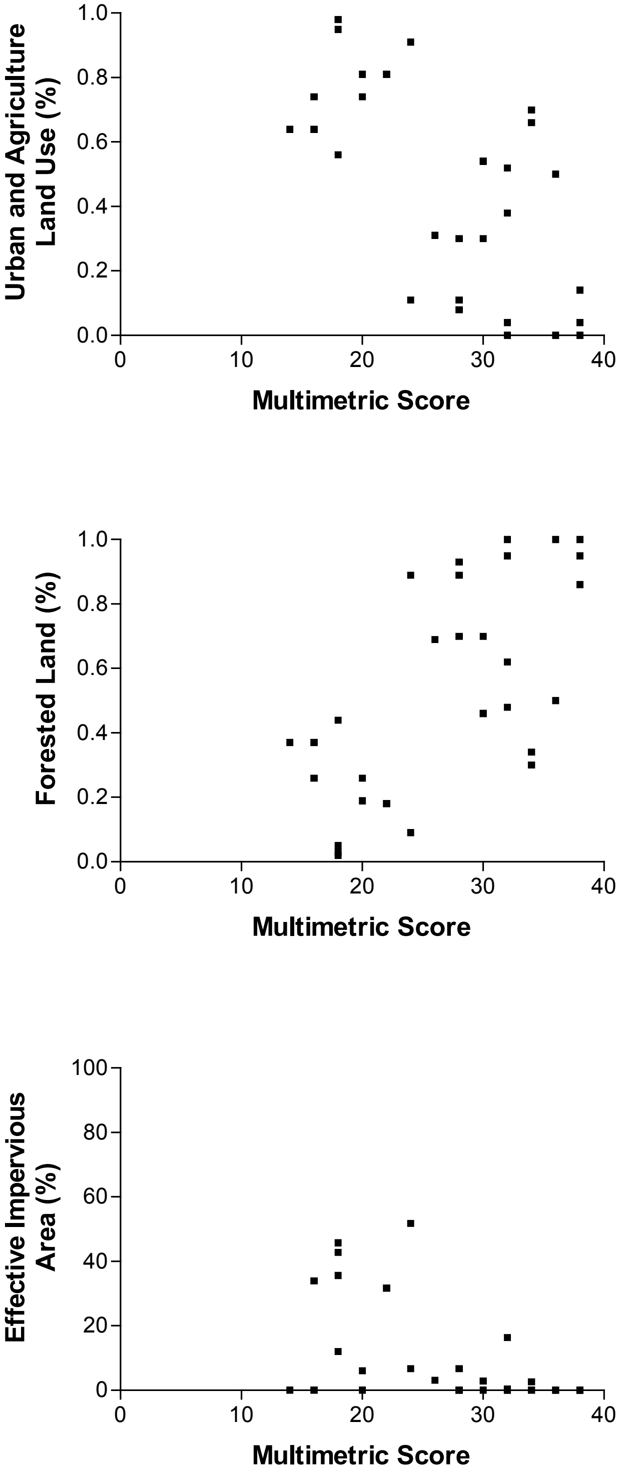

Figure 9. Relationship between macroinvertebrate community multimetric scores and land-use variables found to be significantly correlated with these scores from high-gradient stream reaches sampled in the Tualatin River basin, Oregon, fall 2001.

Table 10. Means, ranges, and correlation with multimetric scores of selected environmental variables measured at 26 high-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Asterisks (*) following p-values indicate significant correlation at alpha = 0.01.

			Correlation with Multimetric Score	
Variable	Mean	Range	Spearman's rho	P value
Urban (%)	14.8	0.0–80.0	-0.547	<0.001*
Agriculture (%)	27.4	0.0–71.0	-0.217	0.125
Forest (%)	53.2	2.0–100.0	0.656	<0.001*
Effective Impervious Area (%)	10.0	0.0–51.8	-0.521	0.002*
Urban, Roads, and Ag (%)	46.8	0.0–98.0	-0.656	<0.001*
Reach gradient (% slope)	3.2	1.5–5.0	0.469	0.005*
Wetted width (m)	3.3	0.9–9.4	0.364	0.024
Coarse substrate (%)	60.7	2.2–93.3	0.621	<0.001*
Sand and fines (%)	20.1	1.1–78.8	-0.579	<0.001*
Embeddedness (%)	45.6	12.1–92.0	-0.540	0.001*
Riparian Buffer Width (m)	74	1.5–152.4	0.502	0.002*
Riparian tree cover (%)	68.9	5.0–90.0	0.660	<0.001*
Nonnative riparian cover (%)	17.6	0.0–65.0	-0.688	<0.001*
Water temperature (^{o}C)	13.6	9.5–19.7	-0.490	0.003*
Specific Conductance (µS/cm)	128.8	49.0–252.4	-0.587	<0.001*
Dissolved oxygen (% sat)	86.1	50.8–105.1	0.433	0.008*

conditions. Among these variables, percent urban and percent forested land uses, measures of stream substrate composition, measures of riparian zone vegetative conditions, and specific conductance showed the strongest correlation with multimetric scores, all with correlation p values < 0.001.

COMPARISON OF YEAR 2000 AND 2001 RESULTS

Total taxa richness, EPT richness, and modified HBI scores from low-gradient reaches were lower, lower, and higher, respectively in 2001 than in 2000 (Figure 10). Paired t-tests indicated that 2001 HBI scores were significantly higher in 2001 than in 2000 (p = 0.014), and that taxa richness in low-gradient reaches was significantly

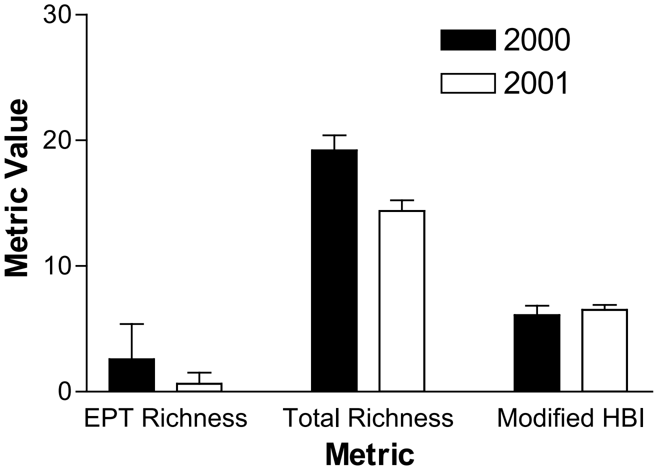

Figure 10. Mean taxa richness, modified HBI scores, and EPT richness of macroinvertebrate communities sampled from low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2000 and fall 2001.

lower in 2001 than in 2000 (p = 0.001). EPT richness was also significantly lower in low-gradient reaches in 2001 than in 2000, as indicated by a paired t-test (p = 0.001).

DISCUSSION

The wide variation in macroinvertebrate community composition exhibited by Tualatin River basin streams is related to both natural variation in land form and resulting stream morphology, as well as by degraded habitat and water quality and altered hydrology resulting from human activities. Multivariate pattern analysis of all reaches and subsequent correlation with environmental variables showed highly significant correlations between major gradients in community composition and a number of environmental variables. These variables included those that describe natural variation (e.g., gradient), those that primarily measure degree of human alteration of the surrounding landscape (e.g., land use, EIA, and riparian zone conditions), and those that are highly influenced by both natural and human forces (e.g., substrate composition). Because so many of these factors are correlated among themselves, assigning cause to certain ones is a tenuous task beyond the design and scope of this type of study. What becomes clear, however, is that as whole, land-use type and intensity (the ultimate causes) have had a measurable effect on physical habitat and water quality (proximate causes) in basin streams, which in turn, has measurably impaired biological integrity. One aspect of disturbance not measured directly in this study, yet known to significantly affect both the form and function of streams, is hydrologic modification by urban and agricultural land uses. Urban development, in particular, significantly alters stream hydrology. Physical data from Seattle area watersheds indicate that EIA levels of less than 10% can cause significant habitat degradation to sensitive waterbodies as a result of altered hydrology (Booth and Jackson 1997).

High-gradient streams exhibited such a wide range in community conditions, that some reaches, including upper Fanno and Golf creeks, had macroinvertebrate communities that closely resembled those sampled from low-gradient reaches. High-gradient reaches that support the richest and most sensitive macroinvertebrate communities can be characterized as having intact and mature riparian zones, low levels of substrate embeddedness, high dissolved oxygen concentrations, low water temperatures, high percentages of coarse substrates (coarse gravel, cobble, and boulder), and they typically occur in heavily forested drainages (Figure 11). Multimetric scores were highly correlated with all of these environmental variables, indicating that as physical and chemical conditions have become impaired by increased land-use intensity across the basin, macroinvertebrate communities also have been compromised. It should be noted that all of these measured relationships are only correlative and, therefore, do not establish cause and effect. For example, specific conductance was highly correlated with multimetric scores, yet macroinvertebrates are relatively insensitive to the range of conductivities occurring in the sample reaches (EPA 1991). In this case, conductivity is simply covarying with other factors that do influence macroinvertebrate community structure, perhaps dissolved oxygen or one or more unmeasured water quality variables.

Low-gradient reaches exhibited a much more narrow range in both physical and benthic community conditions than did high-gradient reaches. Land use was predominantly agricultural, urban, or a mix of the two immediately above every low-gradient reach, as combined urban and agricultural land use averaged 84% above low-gradient stream reaches and only 47% above high-gradient stream reaches. Biological conditions in low-gradient reaches varied just enough to allow analyses to relate gradients in community composition to environmental variables and land use. Although EPT and other sensitive taxa were absent from many low-gradient reaches, reaches still ranged in their taxa composition and collective tolerance to disturbance enough to produce patterns in community condition that were related to certain environmental gradients. Percent fine substrate, percent urban land use, EIA, and dissolved oxygen concentrations all were correlated with major patterns in community composition identified by NMS axes two and three for low-gradient reaches. Individual metrics and overall metric ranks of low-gradient stream conditions also were highly

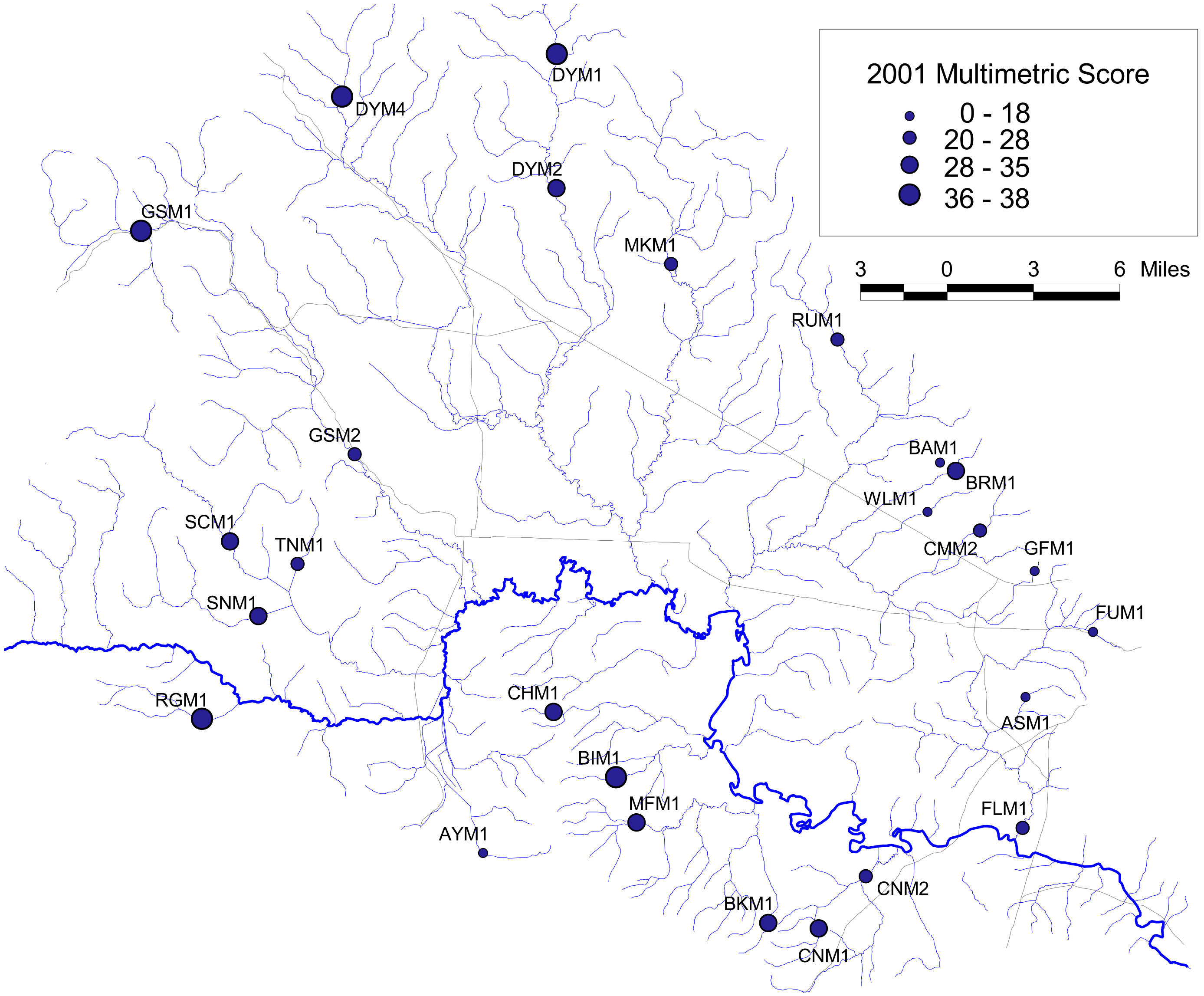

Figure 11. Location of high-gradient stream reaches sampled for macroinvertebrate community conditions in the Tualatin River basin, Oregon, fall 2001. Circle size coincides with stream condition classification: smallest circles indicate severe impairment and largest circles represent minimal impairment.

correlated with NMS ordinations, indicating that that the two approaches to analyzing benthic communities in low-gradient streams were producing similar results, thereby strengthening our ability to draw conclusions from the results of this study.

Overall rankings of low-gradient reaches ranged from 4.8 to 21.5, but because ranking does not provide a measure of absolute difference in conditions among reaches, the ranked list of reaches should be interpreted with care. In general, this approach of ranking reaches is of limited use because the ranks cannot be used to make comparisons with reaches other than those in the ranked group (i.e., sampled at other times or from other locations). It should be stressed that low-gradient reaches did not vary as widely in community composition as did high-gradient reaches; therefore, reaches with relatively dissimilar mean ranks may have only subtle differences in actual community composition. Those reaches ranked at the top of the list, including lower Scoggins, lower Chicken, middle Mckay, middle Dairy, Johnson (north), lower Gales, middle Heaton, middle Bronson, and lower Saum creeks, also occurred towards the upper right-hand corner of the NMS plot; both analyses indicate that these reaches support benthic communities in better condition than in other sampled low-gradient reaches. Reaches ranking lower on the list did not show as clear a relationship with location on the ordination plot and, therefore, share very similar macroinvertebrate communities, despite receiving ranks between 10.2 and 21.5.

Because patterns in community composition were related to environmental conditions in low-gradient reaches, and a number of metrics also were correlated with major patterns in macroinvertebrate community composition, we suggest the continued use of a number of these metrics that are most appropriate for describing the range of conditions occurring in low-gradient reaches on the basin valley floor. In doing so, the condition of each reach can be monitored over time with these metrics that have been shown to be related to major patterns in macroinvertebrate community composition in the lower basin.

Without reference condition information for low-gradient Willamette Valley streams, assessment tools based on comparison to a desired or reference condition cannot be developed. The metrics tested in this study offer a tool for evaluating the condition of streams in the absence of calibrated multimetric and multivariate tools that compare observed to expected conditions. Oregon DEQ has recently located and sampled from what they consider low-gradient reference conditions elsewhere in the Willamette Valley (Rick Hafele, DEQ, personal communication), but how well the data might apply to Tualatin Valley streams has yet to be determined. Until then, examining relationships between gradients in environmental conditions and benthic community structure, and continued use of appropriate metrics provides an effective approach to evaluating macroinvertebrate community conditions in these low-gradient streams.

Low-gradient, valley floor reaches typically are subjected to high water temperatures, low dissolved oxygen, extreme variation in discharge, and other environmental extremes that have been exacerbated by human development of the valley floor. The results of this study show strong relationships between environmental conditions and macroinvertebrate community condition. Although there is no current reference data set or condition with which to assess low-gradient valley floor streams, the range in low-gradient stream conditions and the relationship of these conditions to substrate composition, dissolved oxygen, and other environmental variables indicates that most, if not all, of these systems occurring below developed land uses are degraded to various degrees. A number of low-gradient stream reaches had dissolved oxygen saturations of less than 20%, and one reach (upper Rock Creek, RUM2) was 6%. Such environmental extremes most certainly did not occur in these streams prior to European settlement, and aquatic communities have been measurably impaired as a result of more than 150 years of intensifying land use.

Comparison of 2000 and 2001 data collected from low-gradient reaches indicates that low-gradient reaches in 2001 were, on average, in slightly poorer condition than in 2000. We chose to use only the low-gradient data in this assessment because different habitats were sampled from high-gradient reaches in 2000 and 2001. Intra-site differences between years can be produced by 1) sampling error, 2) variability in sampling methods, 3) real differences in community composition between years, or 4) some combination of the three. Thus, there is a risk of misinterpreting the cause of inter-annual differences in community attributes, particularly in low-gradient reaches, where temperature, flow, and other environmental extremes would be most pronounced in a drought year, as occurred in 2001. In general, reaches had lower overall taxa richness and higher modified HBI scores in 2001 than in 2000. The unidirectional nature of differences between 2000 and 2001 suggests that these differences are likely being produced by real changes in one direction (towards less rich, more disturbance tolerant communities during drought conditions), rather than by random sampling error, which should produce random variation in metric scores between years. Both this year's and last year's duplicate samples produced very similar taxonomic lists and metric scores, indicating that the current sampling protocol is capable of obtaining representative samples of macroinvertebrate communities in study reaches.

As further evidence for having measured the effect of drought on macroinvertebrate communities in the basin, EPT richness was noticeably lower in low-gradient streams in 2001, accounting for much of the reduction in overall taxonomic richness between years. Mayfly, stonefly, and caddisfly taxa collectively are known to be among the most sensitive macroinvertebrates to disturbance and environmental extremes. It is plausible that environmental conditions exceeded the tolerance limits of these taxa in the low-gradient streams in late summer 2001, reducing their abundance in these areas. This has significant implications for biomonitoring in low-gradient Tualatin Valley reaches, especially in regard to timing of sampling episodes, and in furthering our understanding of the distributional limits of sensitive taxa in these valley floor streams.

One objective of this study was to examine relationships between environmental variables and macroinvertebrate community composition in low-gradient reaches. This objective was set forth with the intent to gain a better understanding of what type of macroinvertebrate communities are supported by various land-use types, riparian management practices, and instream physical and chemical conditions. Because we attempted to examine such relationships during a drought year, it appears likely that reaches that support more sensitive taxa and a richer community during less extreme conditions were sampled when biological conditions were worse than they would be in a year with normal rainfall. If drought conditions of late summer 2001 further compromised biological conditions in low-gradient streams, as our data suggest they did, then years or seasons of less extreme environmental conditions should be support richer, but more sensitive communities. Examining communities during less extreme periods, such as early summer, well after spring flooding, yet before drought conditions ensue, would allow distributional patterns of sensitive organisms in the basin to be examined in relation to shifts in environmental gradients. Collective changes in the distribution of sensitive organisms would produce measurable changes in community composition that could also be related back to environmental conditions at that time. Most importantly, this information would provide a better understanding of what environmental conditions in low-gradient streams are required for supporting more healthy and diverse macroinvertebrate communities.

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Appendix 1. Environmental variables measured at 37 low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Coding is as follows: Valley Type: 1 = V shape, 2 = U shape, 3 = ponded, 4 = floodplain; Channel types from Rosgen (1996); dominant erosional and depositional materials: 1 = clay, 2 = sand, 3 = gravel, 4 = cobble, 5 = bedrock, 6 = riprap, 7 = hardpan; adjacent land use: 1 = residential, 2 = industrial/commercial, 3 = agricultural, 4 = undeveloped/forested.

Site Code	Forest %	Agriculture %	Urban %	Roads %	EIA (%)	Reach Length (m)	Valley Type	Channel Type	Reach Gradient (%)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Mean Water Depth (cm)	% Riffles	% Pools	% Glides/Runs	Dominant Eros Material	Dominant Depositional Material	% Coarse Substrate	% Fine Gravel/Sand/Fines	% Sand/Fines
ASM2	3%	7%	66%	24%	51	50	4	F6	1	2.5	3.5	0.5	12.3	10	0	90	4	4	24.4	60.0	47.8
BCM1	6%	17%	65%	12%	31	65	4	F6	0.5	6.8	8.9	1.0	24.4	10	30	60	1	1	11.1	76.7	58.9
BRM2	3%	16%	60%	21%	40	50	4	E6	1	2.4	3.4	0.4	9.7	5	40	55	3	1	7.8	78.9	43.3
BUM1	22%	2%	64%	12%	39	60	4	E6	1	5.8	6.5	1.0	22.5	0	30	70	1	1	40.0	48.9	46.7
BUM2	35%	11%	42%	12%	39	70	3	E6	1	6.8	7.2	0.9	45.1	0	75	25	3	1	0.0	100.0	100.0
CDM1	21%	63%	0%	16%	5	50	1	E6	1	1.8	3.2	0.8	11.9	5	25	70	0	1	0.0	95.6	84.4
CDM2	23%	35%	31%	11%	20	50	4	E6	1	4.3	4.9	0.9	26.9	0	40	60	0	1	2.2	76.7	76.7
CHM2	27%	68%	0%	5%	0	50	1	F6	0.5	5.7	7.3	0.7	30.1	0	0	100	2	1	0.0	83.3	83.3
CLM1	6%	46%	43%	5%	14	50	4	E6	1	2.0	2.4	0.7	10.3	0	30	70	0	1	0.0	88.9	88.9
CMM1	4%	11%	62%	22%	52	50	4	E6	1.5	3.5	4.5	0.7	39.1	0	90	10	3	3/1	2.2	84.4	84.4
CNM3	11%	76%	7%	6%	6	50	4	F6	1	2.2	3.9	0.8	17.1	5	30	65	3	1	14.4	42.2	26.7
DNM1	1%	27%	66%	6%	50	50	4	E6	1	3.4	7.4	0.7	24.2	10	20	70	3	1	1.1	90.0	90.0
DNM2	10%	24%	55%	12%	33	50	4	E6	1	2.3	2.9	0.5	12.7	10	20	70	0	1	0.0	82.2	80.0
DYM3	1%	94%	0%	5%	2	70	4	F6	1	6.1	8.1	1.0	28.1	0	20	80	7	1	0.0	70.0	70.0
DYM5	2%	89%	0%	9%	1	50	4	F6	1	3.9	7.3	7.3	34.2	5	30	65	3	1	3.3	15.6	13.3
FMM1	1%	14%	66%	18%	51	50	1	E6	1.25	2.4	3.3	0.8	12.2	10	30	60	5	5	0.0	62.2	46.7
FUM2	3%	9%	73%	15%	44	50	2	E6	1	3.5	4.7	0.8	21.1	0	50	50	4	3	0.0	68.9	68.9
GSM3	5%	75%	12%	9%	18	60	1	F5	1	8.1	11.8	1.3	28.3	2	23	75	0	1	1.1	76.7	74.4
HDM1	6%	18%	61%	13%	46	50	4	E6	1	1.2	3.0	0.5	5.6	0	100	0	3	1	21.1	76.7	70.0

Appendix 1. (Continued).

Site Code	Forest %	Agriculture %	Urban %	Roads %	EIA (%)	Reach Length (m)	Valley Type	Channel Type	Reach Gradient (%)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Mean Water Depth (cm)	% Riffles	% Pools	% Glides/Runs	Dominant Eros Material	Dominant Depositional Material	% Coarse Substrate	% Fine Gravel/Sand/Fines	% Sand/Fines
HTM1	22%	74%	0%	3%	0	50	1	E6	1	3.0	3.5	0.7	39.1	0	100	0	3	3	0.0	97.8	97.8
JNM1	18%	12%	52%	18%	33	50	1	E6	1.5	1.6	2.3	0.6	13.8	10	30	60	3	1	0.0	88.9	71.1
JSM1	14%	13%	61%	13%	30	50	4	E6	1.5	0.3	0.5	0.3	4.2	5	30	65	0	1	4.4	94.4	77.8
JSM2	7%	3%	59%	21%	43	50	4	E6	1	3.2	4.3	0.4	7.4	0	10	90	3	1	36.7	62.2	26.7
JSM3	2%	5%	75%	18%	43	50	4	E6	1	2.8	3.9	0.7	35.0	0	50	50	1	1	0.0	100.0	100.0
MFM2	25%	72%	0%	4%	0	50	4	F6	1	7.8	9.0	1.3	46.8	0	100	0	3	3	0.0	95.6	94.4
MKM2	17%	81%	0%	2%	0	60	4	F5	1	6.6	8.1	1.1	37.7	0	50	50	3	2	0.0	64.4	64.4
MKM3	11%	59%	21%	8%	24	60	1	E6	1	6.3	9.5	0.8	12.1	10	20	70	1	1	18.9	56.7	51.1
RLM1	10%	15%	64%	11%	51	90	4	F6	0.5	8.8	10.8	1.2	45.3	5	10	85	0	1	0.0	67.8	66.7
RMM1	6%	24%	58%	13%	44	60	4	F6	1.5	5.1	7.0	1.1	34.0	10	30	60	0	1	0.0	85.6	85.6
RUM2	60%	36%	0%	4%	8	50	4	E6	1	3.8	4.9	0.6	30.0		100		3	3	0.0	100.0	100.0
SAM1	17%	24%	32%	27%	15	30	4	E6	1	2.5	3.1	0.5	11.8	0	20	80	4	4	0.0	93.3	88.9
SCM2	57%	33%	0%	4%	0	80	4	F4	1.5	8.1	8.8	1.3	38.6	20	20	60	5	2	24.4	75.6	34.4
SCM3	41%	52%	0%	7%	0	100	4	F6	1	10.1	11.6	1.5	67.5	10	40	50	3	1	13.3	43.3	43.3
SMM1	9%	11%	63%	18%	32	50	1	E6	1	2.3	3.5	0.8	16.9	0	10	90	4	4	3.3	96.7	94.4
SMM2	7%	10%	67%	15%	46	50	4	E6	1	3.6	4.3	0.9	23.5	0	40	60	4	3	23.3	60.0	58.9
SVM1	21%	7%	56%	16%	40	50	1	E6	1.5	0.8	4.0	0.3	11.8	0	50	50	7	1	0.0	100.0	100.0
WLM2	3%	10%	69%	18%	44	50	4	E6	0.5	2.2	3.4	0.8	14.6	10	10	80	0	1	0.0	45.6	45.6
ASM1	3%	2%	80%	16%	43	50	4	E4	1.5	0.9	1.5	0.4	10.3	30	20	50	4	3	11.1	83.3	78.9
AYM1	37%	62%	0%	2%	0	50	1	B3	2.5	1.9	3.1	0.5	7.2	50	10	40	4	3	56.7	40.0	23.3
BAM1	44%	24%	27%	5%	12	50	1	C4	2	1.0	3.0	0.6	15.5	40	30	30	4	4	7.8	91.1	52.2
BIM1	50%	50%	0%	0%	0	50	2	A1	5.5	1.5	4.3	0.3	2.6	70	30	0	3	1	10.0	17.8	8.9
BKM1	46%	54%	0%	0%	3	50	2	B3	5	2.2	3.4	0.3	2.4	80	10	10	3	2	82.2	17.8	4.4

Appendix 1. (Continued).

Site Code	Forest %	Agriculture %	Urban %	Roads %	EIA (%)	Reach Length (m)	Valley Type	Channel Type	Reach Gradient (%)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Mean Water Depth (cm)	% Riffles	% Pools	% Glides/Runs	Dominant Eros Material	Dominant Depositional Material	% Coarse Substrate	% Fine Gravel/Sand/Fines	% Sand/Fines
BRM1	48%	34%	14%	4%	16	50	1	C3	3.5	1.5	2.6	0.5	8.6	50	40	10	4	4	51.1	47.8	36.7
CHM1	34%	64%	0%	2%	0	50	1	B4	4	1.4	2.2	0.3	1.9	60	10	30	3	1	55.6	43.3	31.1
CMM2	18%	5%	65%	11%	32	50	1	B3	4	2.2	3.5	0.6	8.3	50	20	30	4	3	75.6	24.4	14.4
CNM1	30%	70%	0%	0%	3	50	2	A3	5	2.3	4.4	0.5	3.3	70	10	20	3	1	65.6	34.4	7.8
CNM2	19%	71%	6%	4%	6	50	4	G5	2	2.2	3.0	0.7	5.4	15	10	75	1	1	2.2	86.7	62.2
DYM1	100%	0%	0%	0%	0	70	2	B3	3	6.9	12.2	0.9	13.9	70	10	20	0	1	87.8	8.9	1.1
DYM2	62%	35%	0%	3%	0	71	4	C3	2.5	7.0	13.8	0.9	13.8	50	10	40	3	1	64.4	6.7	5.6
DYM4	86%	5%	0%	9%	0	50	1	B3	3	2.1	4.7	0.7	6.3	25	50	25	3	1	84.4	14.4	6.7
FLM1	9%	8%	67%	16%	52	60	1	E3	1.5	5.6	8.7	1.1	16.2	15	15	70	3	3-1	56.7	43.3	30.0
FUM1	5%	4%	63%	28%	46	50	1	B3	2.5	2.2	3.6	0.6	7.7	25	40	35	4	1	46.7	44.4	27.8
GLM1	26%	6%	56%	12%	34	50	2	A1	4	1.6	2.5	0.4	4.6	50	20	30	0	1	32.2	43.3	27.8
GSM1	95%	0%	0%	4%	0	75	2	B3	3.5	6.8	11.3	0.7	13.6	50	30	20	2	1	74.4	25.6	11.1
GSM2	26%	71%	0%	3%	0	110	3	F4	1.5	9.5	17.1	1.1	12.9	40	0	60	1	1	47.8	51.1	13.3
MFM1	70%	30%	0%	0%	0	50	1	B4	3.5	2.5	4.3	0.3	4.5	50	40	10	5	5	70.0	30.0	17.8
MKM1	69%	31%	0%	0%	3	50	4	C4	2	5.6	8.0	0.7	19.1	25	35	40	0	2	56.7	33.3	22.2
RGM1	100%	0%	0%	0%	0	50	4	B3	3	3.4	5.5	0.6	17.5	50	40	10	0	1	47.8	27.8	14.4
RUM1	89%	11%	0%	0%	7	50	1	B1	3.5	3.5	5.4	0.4	5.4	40	40	20	3	2-3	35.6	21.1	14.4
SCM1	100%	0%	0%	0%	0	50	1	B3	4	5.9	12.8	0.9	10.8	70	20	10	3	1	83.3	15.6	3.3
SNM1	95%	4%	0%	0%	0	60	1	B3	4	6.9	9.9	0.8	8.2	75	15	10	3	1	84.4	13.3	5.6
TNM1	93%	6%	0%	2%	0	50	1	A4	4	1.9	3.2	0.7	12.0	35	20	45	0	1	33.3	66.7	32.2
WLM1	2%	18%	68%	12%	36	50	4	E4	2	0.9	2.1	0.4	5.5	60	20	20	3	1	23.3	70.0	14.4

Appendix 1. (Continued).

Site Code	% Fines	% Bedrock	% Hard Pan	% Embeddedness	Large Wood Tally	Organic Layer Accumulation (cm)	% Filamentous Algae	% Macrophytes	Overhead Canopy Cover (%)	Dominant Bank Material	% Stable Bank	% Undercut Bank	Mean Riparian Buffer Width (m)	% Tree Cover	% NonNative Vegetation	Dominant Adjacent Land Use	Temperature (C)	pH	Dissolved Oxygen (% sat)	Specific Conductance (µS/cm)	High/Low Gradient Reach
ASM2	37.8	0.0	14.4	71.4	9	0	0	0	89.5	1	95	0	99.1	90	0	3	10.7	7.8	92	190	0
BCM1	58.9	0.0	2.2	80.2	0	3	30	80	75.7	2	20	30	38.1	0	100	1	17.5	6.81	10.8	212	0
BRM2	40.0	0.0	12.2	65.8	2	3	5	5	74.7	1	70	20	9.15	30	20	3	17.9	7.29	71	113	0
BUM1	34.4	0.0	3.3	74.6	30	2	0	0	24.5	2	90	10	19.8	50	10	3	14.7	7.15	76.7	78.6	0
BUM2	100.0	0.0	0.0	100.0	1	0	0	0	79.6	2	50	15	5.34	37.5	30	1	15	7.33	68.3	217	0
CDM1	83.3	0.0	0.0	100.0	7	2	5	30	94.6	1	90	10	30.5	10	80	3	16.6	7.19	26	130	0
CDM2	76.7	0.0	0.0	98.3	5	3	20	15	81.9	2	90	0	61	10	20	1	19.5	7.57	94.7	224	0
CHM2	83.3	0.0	0.0	100.0	50	3	0	5	95.3	1	90	0	22.9	12.5	70	1	16.1	0	49.6	276	0
CLM1	72.2	0.0	0.0	100.0	7	2-4	0	0	34.6	2	40	50	10.7	20	75	3	11.1	7.31	75.7	110	0
CMM1	81.1	0.0	0.0	99.3	8	0	10	0	3.76	2	25	5	38.1	70	10	1	18.2	7.62	83.5	252	0
CNM3	17.8	0.0	42.2	67.9	25	0	0	0	75.8	2	10	10	24.4	77.5	25	3	14.7	7.18	74.8	195	0
DNM1	90.0	0.0	0.0	100.0	10	2	0	0	75.3	1	85	0	45.7	50	0	2	17.9	7.34	61.5	199	0
DNM2	80.0	0.0	8.9	96.0	1	1	10	80	70.6	2	90	0	19.1	10	50	1	18.7	0	50.3	228	0
DYM3	70.0	0.0	21.1	100.0	50	2	0	0	85.8	1	95	30	18.3	30	60	2	15.8	0	27.6	297	0
DYM5	1.1	0.0	78.9	55.9	14	0-3	0	5	78.6	1	40	10	38.1	50	50	1	14.5	7.29	74.6	106	0
FMM1	36.7	0.0	37.8	76.9	7	0	0	0	44.8	3	95	25	122	90	0	4	13	0	76.6	86.3	0
FUM2	68.9	0.0	15.6	91.7	12	0	0	0	88.9	2	90	15	122	85	0	4	12	0	93.5	58.8	0
GSM3	8.9	0.0	0.0	97.9	16	0-4	0	2	77.5	2	10	10	61	62.5	15	4	16	0	62.3	214	0
HDM1	67.8	0.0	0.0	93.9	3	1	5	0	76.5	2	15	10	4.57	55	60	3	16.2	7.2	71.8	185	0

Appendix 1. (Continued).

Site Code	% Fines	% Bedrock	% Hard Pan	% Embeddedness	Large Wood Tally	Organic Layer Accumulation (cm)	% Filamentous Algae	% Macrophytes	Overhead Canopy Cover (%)	Dominant Bank Material	% Stable Bank	% Undercut Bank	Mean Riparian Buffer Width (m)	% Tree Cover	% NonNative Vegetation	Dominant Adjacent Land Use	Temperature (C)	pH	Dissolved Oxygen (% sat)	Specific Conductance (µS/cm)	High/Low Gradient Reach
HTM1	97.8	0.0	0.0	100.0	5	0	0	0	42	4	90	10	152	80	12.5	4	13	7.54	105	91.1	0
JNM1	40.0	0.0	3.3	95.8	23	0	0	0	89.7	4	90	10	152	80	0	4	14	7.75	95.2	49	0
JSM1	57.8	0.0	0.0	98.2	0	4	0	10	68.5	1	80	0	45.7	30	50	3	13.1		27	293	0
JSM2	20.0	0.0	0.0	90.2	4	0	0	0	55.1	2	90	10	53.4	80	0	3	9.5	7.29	96.4	69.9	0
JSM3	100.0	0.0	0.0	100.0	4	4	0	0	0.98	2	90	30	91.5	30	85	1	15.2	0	54.4	395	0
MFM2	93.3	0.0	0.0	98.7	22	0	0	0	87.9	2	70	0	88.4	65	30	3	16.9	0	95.2	135	0
MKM2	56.7	0.0	11.1	93.7	40	0	0	20	83.7	1	20	0	4.57	45	42.5	3	18.1	0	91.2	82.8	0
MKM3	51.1	0.0	5.6	89.2	2	0	0	0	93.6	2	40	40	4.57	25	20	1	17.2	7.42	79.6	113	0
RLM1	64.4	0.0	31.1	99.4	0	1	0	50	94.9	2	80	0	7.62	25	20	1	21.4	7.54	98	172	0
RMM1	85.6	0.0	6.7	100.0	12	2	0	0	77	2	90	0	24.4	65	20	3	15.4	7.24	58.9	167	0
RUM2	100.0	0.0	0.0	100.0	9	0	0	0	67.5	4	75	10	152	80	0	4	13.3	7.63	99	98.1	0
SAM1	85.6	0.0	0.0	98.4	13	0-1	0	0	49.8	2	85	30	122	70	65	3	14.4	0	88.8	166	0
SCM2	6.7	0.0	0.0	56.1	6	0	0	0	7.35	1	70	15	10.7	70	50	2	19.7	7.68	76.3	244	0
SCM3	42.2	0.0	34.4	76.9	15	1	0	0	58.7	1	40	20	10.7	80	20	2	16.6	0	41.2	281	0
SMM1	88.9	0.0	0.0	100.0	10	0	0	0	54.1	1	90	10	83.8	80	0	4	15.3	7.14	85.5	125	0
SMM2	53.3	0.0	7.8	88.4	5	0	0	0	97.9	2	25	10	30.5	80	25	1	13.7	7.41	83.7	154	0
SVM1	100.0	0.0	0.0	100.0	1	0	5	0	18.5	1	20	10	38.1	10	30	1	16	7.36	36.4	388	0
WLM2	45.6	0.0	42.2	81.2	25	2-4	0	0	69.6	2	80	15	22.9	60	50	3	15.2	0	27.3	163	0
ASM1	78.9	0.0	5.6	92.0	0	0	0	0	48.9	2	75	20	51.8	75	0	4	9.8	7.26	89.9	100	1
AYM1	6.7	0.0	2.2	49.1	15	0	0	0	98.2	1	90	0	87.7	85	0	4	13	7.75	95.4	92.8	1
BAM1	33.3	0.0	0.0	86.0	11	0	0	0	99.7	2	100	5	107	80	0	4	10.4	7.52	94.3	70.8	1
BIM1	0.0	66.7	0.0	21.1	0	1-2	0	25	99	2	90	0	1.52	5	25	1	14	7.36	50.8	136	1
BKM1	1.1	0.0	0.0	19.4	0	0-1	0	10	99.7	2	90	50	12.2	2.5	80	2	0	0	101	82.8	1

Appendix 1. (Continued).

Site Code	% Fines	% Bedrock	% Hard Pan	% Embeddedness	Large Wood Tally	Organic Layer Accumulation (cm)	% Filamentous Algae	% Macrophytes	Overhead Canopy Cover (%)	Dominant Bank Material	% Stable Bank	% Undercut Bank	Mean Riparian Buffer Width (m)	% Tree Cover	% NonNative Vegetation	Dominant Adjacent Land Use	Temperature (C)	pH	Dissolved Oxygen (% sat)	Specific Conductance (µS/cm)	High/Low Gradient Reach
BRM1	35.6	0.0	0.0	65.8	2	0.25	0	0	93.5	4	95	5	68.6	90	30	3	13.1	7.51	85.6	73.4	1
CHM1	31.1	0.0	0.0	70.4	11	0	0	0	97.4	2	80	20	83.8	32.5	25	4	12.6	7.76	87	190	1
CMM2	5.6	0.0	0.0	51.2	9	0	0	0	82	1	80	10	41.2	45	60	1	17.2	8.01	93.8	205	1
CNM1	2.2	0.0	0.0	35.2	12	0	0	0	93.8	1	40	10	61	75	10	1	14.8	7.34	70.9	96.9	1
CNM2	36.7	0.0	0.0	88.4	15	0.5	10	10	95.1	2	20	0	9.15	70	20	1	16.4	7.11	31.4	233	1
DYM1	0.0	3.3	0.0	15.1	11	0-2	0	0	96.1	2	10	0	22.9	55	10	3	13.6	0	6.2	198	1
DYM2	4.4	28.9	0.0	12.1	9	0.2	30	0	89.1	2	85	5	15.2	50	25	3	16.8	0	71.3	309	1
DYM4	3.3	0.0	0.0	30.6	8	1	0	25	93.5	1	30	0	4.57	60	25	1	17.7	7.21	43.9	200	1
FLM1	12.2	0.0	1.1	57.0	10	3	60	40	93.3	1	95	5	25.9	25	60	2	17.5	7.39	37.3	621	1
FUM1	5.6	0.0	6.7	65.7	4	1-2	0	0	99.2	2	85	20	61	55	25	1	15.2	7.29	53.3	165	1
GLM1	8.9	20.0	4.4	53.7	7	0	0	25	95.8	2	35	0	9.15	40	30	1	14.2	7.26	64	184	1
GSM1	1.1	0.0	0.0	32.4	50	0	0	0	97.2	1	10	0	38.1	55	20	1	18.6	7.48	71	148	1
GSM2	0.0	0.0	0.0	36.2	4	0	0	0	52.1	2	15	0	2.29	15	65	2	14.7	6.95	54	133	1
MFM1	17.8	0.0	0.0	52.9	3	0	0	0	96.2	2	90	20	64	75	0	4	11.8	7.65	95	88.2	1
MKM1	2.2	0.0	5.6	50.2	9	0	0	0	52.8	1	10	20	19.1	50	60	1	14	7.42	78.2	106	1
RGM1	6.7	20.0	0.0	34.2	0	0-0.5	10	50	100	1	60	0	17.5	55	25	1	16.1	0	61.6	255	1
RUM1	10.0	43.3	0.0	33.3	18	0	0	0	96.4	2	90	10	32	15	50	3	14.6	7.31	88.8	92.1	1
SCM1	0.0	1.1	0.0	13.4	2	0	20	20	94.8	2	90	10	12.2	40	57.5	1	16.6	7.56	79.3	142	1
SNM1	0.0	2.2	0.0	27.8	30	1	0	5	91.8	2	85	10	19.8	37.5	55	1	16.8	0	57.6	125	1
TNM1	17.8	0.0	0.0	70.6	2	1	0	0	84	2	60	0	7.62	15	60	1	17.4	7.59	6.48	227	1
WLM1	11.1	0.0	3.3	49.3	8	0	0	0	95.8	1	10	0	6.1	70	0	3	15.7	7.19	67.8	108	1

Appendix 2. Metrics calculated from macroinvertebrate communities sampled from 37 low-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Reaches with two digits following the three-letter site code are duplicate samples.

Site Code	Taxa Richness	EPT Richness	% Chironomidae	% Molluska	% Oligochaeta	% Dominant	% Tolerant	% Sediment Tolerant	Modified HBI	Overall Rank
ASM2	15	1	24.5	62.5	10.6	34	93	73	6.6	13.3
BCM1	11	0	2.3	81.1	9.1	41	75	69	6.9	13.0
BRM2	22	2	29.1	36.9	19.9	20	80	57	6.6	8.0
BUM1	14	0	0.8	45.2	9.8	41	92	50	6.3	11.8
BUM2	10	0	47.5	7.9	27.1	38	92	35	7.4	12.5
CDM1	20	2	53.3	19.3	19.1	46	90	38	6.5	10.3
CDM2	16	0	25.5	56.6	15.4	45	95	71	6.4	14.2
CHM2	12	0	83.6	7.5	0.5	71	89	8	9.3	15.0
CLM1	14	0	7.6	32.6	29.9	30	74	63	6.9	10.3
CMM1	19	1	22.3	48.5	15.6	43	85	64	7.8	13.3
CNM3	16	2	31.0	17.0	21.0	21	42	37	6.4	5.3
DNM1	17	0	7.6	71.8	9.5	53	96	81	5.9	15.8
DNM2	14	0	26.4	48.4	18.3	45	96	67	7.1	15.3
DYM3	10	0	7.5	57.5	25.8	48	87	83	7.2	16.8
DYM5	17	4	25.7	43.2	3.9	33	70	48	5.1	6.7
FMM1	13	0	2.0	83.9	10.7	52	97	92	6.5	18.2
FUM2	13	0	8.4	82.2	7.6	67	90	90	5.6	16.7
GSM3	13	1	50.0	22.9	8.6	46	41	31	6.1	7.5
HDM1	25	1	7.2	59.4	12.3	44	87	72	7.2	12.7
HTM1	16	2	63.5	29.1	0.0	35	60	29	7.1	7.5
JNM1	16	1	48.2	11.0	38.2	38	50	49	5.0	7.0
JSM1	22	1	44.1	52.2	0.7	52	68	53	7.3	11.3
JSM21	15	0	47.3	26.0	6.2	38	79	32	8.2	11.0
JSM22	15	0	37.0	29.8	8.8	28	77	39	7.8	12.8
JSM3	9	0	23.0	38.5	31.1	31	85	57	7.5	14.5
MFM2	12	0	76.6	10.0	10.4	47	96	20	8.5	5.3
MKM2	18	2	37.7	23.8	20.0	27	59	43	5.7	11.5
MKM3	10	1	4.5	43.8	26.8	27	88	71	6.1	12.2
RLM1	15	0	7.4	30.9	28.7	32	94	59	6.7	17.2
RMM1	11	0	7.7	72.5	16.2	57	89	89	6.5	21.5
RUM2	9	0	4.2	76.9	13.5	77	96	91	7.7	9.2
SAM1	18	1	33.9	49.7	7.8	28	77	57	6.8	14.3
SCM21	20	1	10.9	79.1	1.0	64	83	80	6.4	4.8
SCM22	23	3	19.2	67.5	0.6	50	75	68	6.4	20.0
SCM3	24	7	13.5	44.6	0.5	30	61	45	5.7	16.7
SMM1	8	0	6.1	73.5	0.0	62	98	74	7.6	18.8
SMM2	12	0	9.3	69.2	10.3	53	92	78	6.8	15.2
SVM1	13	0	0.6	94.2	2.2	54	96	93	6.7	13.3
WLM2	15	1	6.6	58.2	28.2	39	93	86	6.8	13.0

Appendix 3. Metrics (and standardized scores) calculated from macroinvertebrate communities from 26 high-gradient stream reaches in the Tualatin River basin, Oregon, fall 2001. Reaches with two digits following the three letter site code are duplicate samples.

Site	Taxa Richness		Mayfly Richness		Stonefly Richness		Caddisfly Richness		Number of Sensitive Taxa		Number Sediment Sens Taxa		Modified HBI		% Tolerant		% Sediment Tol		% Dominant (single taxon)		Multimetric Score
ASM1	16	(1)	1	(1)	0	(1)	0	(1)	0	(1)	0	(1)	6.6	(1)	12.9	(5)	12.4	(3)	29.4	(3)	18
AYM11	20	(3)	1	(1)	3	(3)	3	(1)	0	(1)	0	(1)	6.5	(1)	89.5	(1)	84.5	(1)	84.4	(1)	14
AYM12	25	(3)	3	(1)	3	(3)	5	(3)	0	(1)	0	(1)	5.5	(1)	68.9	(1)	58.3	(1)	58.3	(1)	16
BAM1	22	(3)	1	(1)	2	(1)	3	(1)	0	(1)	0	(1)	5.4	(1)	17.6	(3)	17.9	(3)	30.6	(3)	18
BIM1	34	(3)	5	(3)	6	(5)	7	(3)	3	(3)	1	(3)	5.0	(3)	3.9	(5)	4.6	(5)	34.6	(3)	36
BKM11	39	(5)	7	(3)	6	(5)	7	(3)	2	(3)	0	(1)	5.6	(1)	27.9	(3)	11.3	(3)	23.6	(3)	30
BKM12	31	(3)	5	(3)	5	(3)	5	(3)	2	(3)	0	(1)	4.7	(3)	9.3	(5)	0.6	(5)	40.3	(1)	30
BRM1	33	(3)	4	(3)	3	(3)	4	(3)	1	(1)	0	(1)	3.8	(5)	8.5	(5)	7.3	(5)	22.8	(3)	32
CHM1	36	(5)	6	(3)	5	(3)	3	(1)	1	(1)	1	(3)	4.0	(5)	17.8	(3)	8.7	(5)	12.2	(5)	34
CMM2	12	(1)	1	(1)	0	(1)	1	(1)	0	(1)	0	(1)	4.9	(3)	1.0	(5)	1.0	(5)	37.2	(3)	22
CNM1	32	(3)	7	(3)	6	(5)	5	(3)	0	(1)	1	(3)	4.3	(3)	12.4	(5)	4.2	(5)	35.2	(3)	34
CNM2	25	(3)	3	(1)	3	(3)	3	(1)	0	(1)	0	(1)	5.5	(1)	30.7	(3)	12.9	(3)	26.2	(3)	20
DYM1	31	(3)	9	(5)	4	(3)	9	(5)	1	(1)	1	(3)	4.0	(5)	6.0	(5)	0.5	(5)	34.9	(3)	38
DYM2	28	(3)	4	(3)	4	(3)	5	(3)	0	(1)	1	(3)	4.6	(3)	8.4	(5)	3.4	(5)	28.3	(3)	32
DYM4	40	(5)	7	(3)	4	(3)	9	(5)	1	(1)	2	(5)	3.6	(5)	16.8	(3)	11.8	(3)	13.9	(5)	38
FLM1	19	(3)	2	(1)	0	(1)	2	(1)	0	(1)	0	(1)	5.9	(1)	13.2	(5)	2.3	(5)	18.3	(5)	24
FUM1	12	(1)	1	(1)	0	(1)	0	(1)	0	(1)	0	(1)	5.2	(1)	3.3	(5)	2.2	(5)	78.8	(1)	18
GLM1	11	(1)	1	(1)	0	(1)	0	(1)	0	(1)	0	(1)	6.0	(1)	21.7	(3)	5.2	(5)	68.9	(1)	16
GSM1	38	(5)	10	(5)	6	(5)	8	(3)	1	(1)	1	(3)	4.4	(3)	2.3	(5)	1.9	(5)	28.7	(3)	38
GSM2	24	(3)	7	(3)	2	(1)	3	(1)	0	(1)	0	(1)	3.5	(5)	67.4	(1)	12.1	(3)	54.6	(1)	20
MFM11	34	(3)	4	(3)	3	(3)	6	(3)	1	(1)	1	(3)	4.2	(3)	36.8	(3)	7.1	(5)	27.5	(3)	30
MFM12	33	(3)	6	(3)	5	(3)	5	(3)	1	(1)	1	(3)	4.7	(3)	16.9	(3)	12.6	(3)	36.1	(3)	28
MKM1	27	(3)	4	(3)	4	(3)	3	(1)	0	(1)	1	(3)	4.3	(3)	30.1	(3)	10.4	(3)	33.8	(3)	26
RGM1	30	(3)	9	(5)	5	(3)	7	(3)	2	(3)	1	(3)	4.0	(5)	14.2	(5)	11.2	(3)	31.5	(3)	36
RUM11	24	(3)	3	(1)	4	(3)	5	(3)	0	(1)	0	(1)	3.8	(5)	8.2	(5)	6.0	(5)	42.5	(1)	28
RUM12	25	(3)	2	(1)	4	(3)	6	(3)	0	(1)	0	(1)	4.5	(3)	22.5	(3)	20.9	(3)	24.0	(3)	24
SCM1	26	(3)	4	(3)	7	(5)	5	(3)	1	(1)	2	(5)	4.1	(3)	15.5	(3)	13.3	(3)	26.1	(3)	32
SNM1	33	(3)	5	(3)	6	(5)	7	(3)	1	(1)	1	(3)	4.4	(3)	4.4	(5)	2.3	(5)	45.8	(1)	32
TNM1	31	(3)	7	(3)	4	(3)	5	(3)	1	1	1	3	4.9	3	21.2	3	10.6	3	38.5	(3)	28
WLM1	10	(1)	0	(1)	0	(1)	0	(1)	0	1	0	1	5.2	1	25.1	3	4.7	5	30.8	(3)	18