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IMPACT SOURCE DETERMINATION WITH BIOMONITORING DATA IN NEW YORK STATE: CONCORDANCE WITH ENVIRONMENTAL DATA

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ABSTRACT – An Impact Source Determination method, used to identify point and nonpoint sources of impacts to stream water quality on the basis of benthic macroinvertebrates, was examined for concordance with impairment sources inferred from chemical and physical site characteristics, watershed characteristics, and biomonitoring results collected from 26 sites in the Hudson River Basin during 1993-94. Most classifications agreed with the resulting interpretations; site locations on Canonical Correspondence Analysis triplots corresponded with interpretation of environmental gradients as (1) overall pollution including organic enrichment and contaminants from point and nonpoint sources, (2) nonpoint nutrients from both agricultural and urban sources, and (3) sediment and suspended organic carbon from agricultural runoff. High-level taxonomic resolution was important in identifying the environmental gradients, and may be necessary for impairment source identification.

INTRODUCTION

Impact source identification has become an increasingly important issue to the biomonitoring community in the United States and other nations. This is associated in part with the reduction or elimination of impacts from readily identifiable point sources. Future improvements in water resource quality will require discrimination among less readily-identifiable stressors, so that resource-protective and remedial policies can be appropriately targeted. Biomonitoring with macroinvertebrate community data, fish community data, periphyton community data, or combinations of these has a long history of success in establishing the degree of water quality impairment, and, thus, is the mainstay of many water quality monitoring efforts throughout the United States as well as in other countries (reviewed in Davis and Simon 1995), whether through multimetric or multivariate approaches. However, biomonitoring data are, as yet, not widely used in source identification, and the ability of these data to determine the actual source of impairment has been ques-

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tioned (Suter 1993; reviewed in Davis and Simon 1995; reviewed in Yoder and Rankin 1995).

Several examples exist to suggest that biomonitoring data may indeed be suitable for source identification. Ohio EPA's Biological Response Signatures approach distinguishes among several types of stressors (Yoder 1991; Yoder and Rankin 1995). It relates the unique responses of individual metrics from several fish and invertebrate multimetric indices to known impact sources; the multimetric indices include the Index of Biotic Integrity (modified from Karr 1981), the Modified Index of Well-Being, and the Index of Invertebrate Community Integrity. It also brings multiple "lines of evidence" to bear on the problem by use of chemical and physical data and watershed characteristics. Eagleston et al. (1990) used biomonitoring data in North Carolina to compare benthic macroinvertebrate relative abundance patterns with results of toxicity testing downstream of sewage treatment plants and industrial discharges. Community composition and relative abundances of certain taxa provided discriminatory power between impairments associated with organic enrichment and those associated with toxic discharges. However, metrics such as taxa richness and Ephemeroptera, Plecoptera, Trichoptera richness were less useful in distinguishing between these impairment sources. Norton et al. (2000) found that fish and macroinvertebrate metrics for Ohio streams and rivers successfully discriminated among stressors related to impairment of stream corridor structure, nutrient enrichment, siltation, and chemical and biological oxygen demands.

The reduction or elimination of impacts associated with point-source discharges in New York State has resulted in marked improvement in many streams since the 1970s (Bode et al. 1993). Identification and control of impairment from nonpoint-sources, and of relatively subtle impairment from point sources, have emerged as an important focus of New York State Department of Environmental Conservation's (NYSDEC) Stream Biomonitoring Unit. The Impact Source Determination (ISD) methodology was developed in 1994 as a response to this need (Bode et al. 1996). NYSDEC now uses ISD throughout the State, in conjunction with assessment of severity of the water quality impact, to provide an overall assessment of water quality, to discern point and nonpoint stressors, and to target further investigation once potential sources have been identified.

ISD classifies sites into one of 6 impact-source classes or a "natural" class (Table 1). Impact source classes are (1) nonpoint nutrient additions, (2) siltation, (3) toxic, (4) organic (sewage effluent or animal wastes), (5) complex (municipal and/or industrial), and (6) impoundment. Each of these 7 classes consists of 5 to 13 model communities. The heterogeneity of these model communities within an ISD class allows for macroinvertebrate sample differences associated with natural factors such as gradient, elevation, latitude, stream size, and time of year. ISD is similar in some ways to the RIVPACs approach (Wright et al. 1984; Moss et al. 1987) in that new samples are compared with predicted communities (in our case, the ISD model communities). However, RIVPACS is used to classify unpolluted running waters, and to compare new samples against these model reference communities to determine degree of impact. ISD is similar to Ohio's Biological Response Signature (Yoder 1991, Yoder and Rankin 1995), in that it is used to classify pollutional types, but Yoder's system is based on metrics, whereas ISD is based on assemblage relative abundance data.

Qualitative evaluation of ISD suggests that it provides good classifications based on professional judgment and knowledge of the watersheds and likely impairment sources. However, it has not yet been verified by comparison with chemical and physical stream data and watershed characteristics, or with other analyses of the macroinvertebrate data. ISD's verification, refinement, and continual development would be enhanced by comparison with these other lines of evidence. The purpose of this study was, therefore, to examine the degree to which the Impact Source Determination technique developed and employed by New York State Department of Environmental Conservation agrees with chemical, physical, and land use evidence, and other approaches for analysis of the macroinvertebrate data. We evaluate ISD by relating its site classifications to results of multivariate analysis of biological, chemical, physical, and land use data.

Table 1. Descriptions of Impact Source Determination (ISD) classes used by New York State Department of Environmental Conservation for stream biomonitoring.

ISD Class	Description
Natural	Minimal human impacts. Includes pristine stream segments and those receiving discharges that minimally affect the biota.
Nonpoint nutrients	Mostly nonpoint agricultural and sources with similar impacts. Includes row crop runoff, golf course runoff, well-treated sewage effluent, and urban runoff. May include pesticide effects.
Toxic	Industrial, municipal, or urban runoff. May include municipal waste-water treatment plant discharges that include industrial wastes, and (or) are characterized by high ammonia or chlorine levels.
Organic	Sewage effluent and (or) animal wastes. Includes conventional waste-water treatment plant discharges, livestock waste inputs, and failing septic systems.
Complex	Municipal and (or) industrial. Includes industrial point sources and municipal waste-water treatment plant discharges that include industrial wastes. May also include combined sewer overflows and urban runoff.
Siltation	Sites affected by moderate to heavy deposition of fine particles.
Impoundment	Includes upstream lake or reservoir releases, dammed stream segments, or stream segments with upstream areas of natural pond, wetland, or sluggish zones.

ISD models were originally developed from results of 712 riffle kick samples taken from 118 streams throughout New York State during July – September 1983–93 (these same samples were originally used to develop NYSDEC's current multimetric biological impairment criteria, Bode and Novak 1995). The first step in model development was to select, from the pool of 712 samples, 20 samples to represent each impact class. Chemical data, land use characteristics, known point sources, and (or) information regarding indicator organisms in the sample were used to select 20 sites within each ISD class for which the impact source was the most certain. Next, model communities were established within each class by performing cluster analysis on the 20 sites (samples) within each ISD class. Cluster analysis was conducted by use of percent similarity (Whittaker and Fairbanks 1958; Whittaker 1975) of mostly family- and genus- level relative abundances from the 100-specimen subsamples. Resulting clusters were composed of 4–5 sites with high macroinvertebrate-community similarity within each ISD class. A single model community was then formed for each cluster, by using percent relative abundances of primarily family- and genus-level taxa in multiples of 5 (this number was chosen for ease of calculation and to reduce the influence of rare taxa in the samples). Each model was then tested against new sample data from sites with known impacts; some were adjusted to achieve maximum representation of the impact type. ISD's continual development and refinement includes addition of new model communities as new macroinvertebrate data and information about sites and sources are collected, and some modification to include lower taxonomic levels for certain taxa when new information suggests they will help distinguish among impairment sources. New models have been developed over the years when unique communities were recognized that did not exhibit high similarity to existing models, and for which high similarity to other unclassified sites with similar impact type were also found. Most new models were based on at least 5 data sets from different streams with similar impact types. For example, one of the recently developed nonpoint nutrient models is based on a number of sites downstream of golf courses (R.W. Bode, NYSDEC, personal communication). Through this process, ISD has evolved over the years to include 62 models (Bode et al. in press), which are shown in Appendix I. Application of ISD involves determining percent similarity of sample data to each model community. The highest similarity within each ISD class is recorded and compared among ISD classes. The model that exhibits the highest similarity to the test data denotes the likely impact source type, or may indicate "natural" (i.e., lacking an impact). When similarities are compared among ISD classes, those within 5 percent of the highest are also considered relevant. Test data exhibiting less that 50 percent similarity to any model are considered less conclusive than those exhibiting greater similarity.

One way to determine the extent to which source identification is successful would be to compare ISD interpretations with those derived from associated chemical, physical, and hydrologic patterns, in a multiple "lines of evidence" approach, similar to what is done by Ohio EPA with their Biological Response Signatures (Yoder and Rankin 1995). However, relating biomonitoring results to chemical and physical variables can be complicated by the large number of chemical and physical variables often amassed in these types of monitoring programs, and the synergistic and integrative effects of environmental conditions on biota. Multivariate data analysis techniques can help reduce the dimensionality of the environmental data so that the major gradients of variation can be summarized and more clearly displayed. Although there has been much debate concerning the suitability of multivariate techniques in biomonitoring (Norris 1995; Gerritsen 1995; reviewed in Reynoldson et al. 1997), recent papers suggest multivariate and multimetric approaches may be complementary (e.g., Resh et al. 1995). The examination and refinement of ISD seems an appropriate use of a combined approach. A study of relations among periphyton, macroinvertebrates, fish, and chemical and physical conditions of water-column and bottom sediment, habitat, and watershed characteristics of Hudson River Basin (New York) streams was conducted from 1993 to 1995 as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) Program (Wall et al. 1998). At selected NAWQA sites, additional benthic macroinvertebrate samples were collected according to NYSDEC's biomonitoring protocol (Bode et al. 1996). These data were used to classify sites according to ISD, and to calculate biomonitoring indices. ISD classifications of these sites were then compared with macroinvertebrate metrics and indices, habitat and land use characteristics, and with patterns resulting from multivariate analysis of macroinvertebrate and environmental data.

METHODS

Study area

The Hudson River Basin covers 34,447 km^2 in eastern New York State, and parts of Vermont, New Jersey, Massachusetts, and Connecticut. Two (Level III) ecoregions make up most of the Hudson River Basin (Omernik 1987, U.S. Environmental Protection Agency 1998, Fig. 1): the Eastern Great Lakes and Hudson Lowlands ecoregion, and the northeastern Highlands ecoregion. All sites but two, located in the Northeastern Coastal Zone, are located within these areas. Soils throughout most of the study area are well-drained, and are underlain by clastic rock (primarily shale and sandstone). The Adirondack Mountains, in the northern part of the study area, are an exception in that they are largely underlain by crystalline rock. Land use in the Eastern Great

Lakes and Hudson Lowlands ecoregion is primarily agricultural, consisting of dairy farms, row crops, and hayfields. Land use in the Northeastern Highlands ecoregion is largely forested, although there is a mix of agricultural and urban land. Large urban centers are located in each ecoregion within a few miles of the Hudson River and its major tributary, the Mohawk River (Phillips and Hanchar 1996).

Site selection

Twenty-six sites (Fig. 1, Table 2) were selected on wadeable streams that drain watersheds of 28 to 494 km^2. Watershed sizes were restricted to this relatively narrow range to minimize natural variability associated with stream size. Sites were selected to represent streams draining agricultural, forested, residential, and urban settings throughout much of the Hudson River Basin, to include a range of land use intensities, and to distribute, to the extent possible, each type of land use in different parts of the basin and in both of the predominant ecoregions. To maximize our ability to discern patterns and relate them to land use with a relatively small number of sites, we avoided sites with mixed agricultural and urban signatures (which we defined as greater than 10

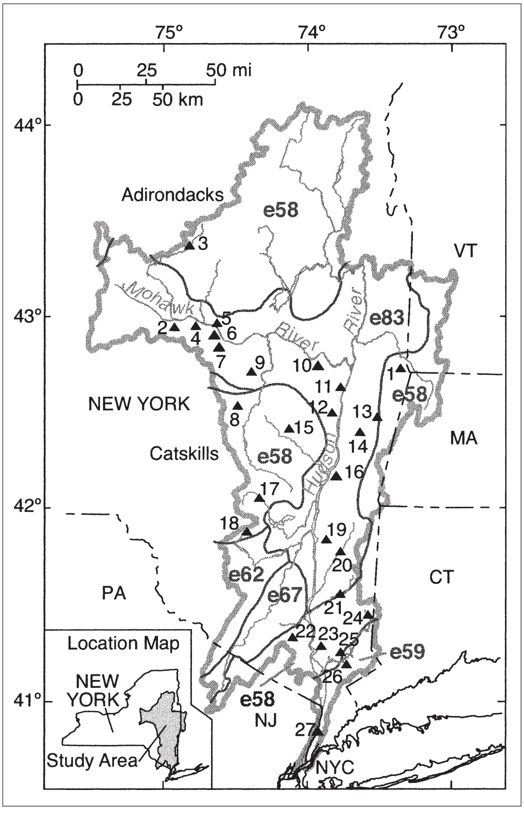


Figure 1. Map of Hudson River Basin (New York, USA) showing sites from which benthic invertebrate, chemical, and physical samples were collected. Site names are given in Table 1. Solid lines separate ecoregions (US EPA 1998): e58= Northeastern Highlands, e59=Northeastern Coastal Zone, e62= North Central Appalachians, e67 = Ridges and Valleys, e83= Eastern Great Lakes and Hudson Lowlands.

Table 2. Watershed characteristics of streams from which benthic invertebrate samples and environmental data were collected in the Hudson River Basin, NY,1993 – 1994.

Site code	U.S.G.S station #	Site name and location	Drainage area (km)	Elevation (m above sea level)	Segment gradient (%)	Human population density (#/km^2)	Urban land (% total area)	Agricultural land (% total area)	Forested land (% total area)	Land use category[1]
1	01333500	Little Hoosic River at Petersburg, NY	141	179	0.6	13	1.8	6.5	91.8	agr
2	0134273950	Fulmer Creek at Days Rock Near Mohawk, NY	29	219	1.2	20	0.3	47.0	52.7	agr
3	01342800	West Canada Creek at Nobleboro, NY	494	423	0.2	0	0.0	0.3	99.7	for
4	01346865	Nowadaga Creek at Newville, NY	56	155	1.3	3	0.5	45.7	53.8	agr
5	01348580	Caroga Creek at Palantine Church, NY	230	104	0.5	17	0.9	17.7	81.4	agr
6	01348995	Otsquago Creek at Valley Brook nr Fort Plain, NY	150	92	0.8	15	0.4	64.9	34.7	agr
7	01349150	Canajoharie Creek near Canajoharie, NY	155	195	0.2	18	1.0	61.1	37.8	agr
8	01350196	West Kill northwest of North Blenheim, NY	98	250	3.5	7	0.2	10.2	89.6	agr
9	01351270	West Creek at Warnersville, NY	135	299	0.9	17	0.4	45.4	54.2	agr
10	01356190	Lisha Kill northwest of Niskayuna, NY	40	76	0.5	522	58.5	6.9	34.4	urb
11	01359135	Patroon Creek at Albany, N.Y.	37	12	2.4	1032	76.8	5.6	17.3	urb
12	01360500	Kinderhook Creek at East Nassau, NY	296	171	1.1	17	3.4	10.5	86.1	agr
13	01361200	Claverack Creek at Claverack, NY	142	43	0.2	37	6.4	22.5	71.0	agr
14	01361500	Catskill Creek at Oak Hill, NY	206	238	0.7	11	0.6	12.4	87.0	agr
15	0136216850	Roeliff Jansen Kill at Jackson Corners, NY	440	90	0.5	19	3.2	27.9	69.0	agr
16	01362200	Esopus Creek at Allaben, NY	165	304	0.9	6	0.3	0.9	98.7	for
17	01364970	Rondout Creek near Sundown, NY	45	360	1.1	<1	0.0	0.0	100.0	for
18	01372051	Fall Kill at Poughkeepsie, NY	49	44	1.0	415	28.0*	6.7*	65.3	urb
19	01372200	Wappinger Creek near Clinton Corners, NY	233	71	0.1	31	1.9	23.9	74.2	agr
20	01372681	Fishkill Creek at Stormville Rd nr Hopewell Jct, NY	141	81	0.2	94	14.6*	9.2*	76.1	urb*
21	01373690	Woodbury Creek near Highland Mills, NY	29	180	1.8	170	18.9	2.7	78.4	urb
22	01374300	Peekskill Hollow Cr at Van Cortlandtville, NY	124	9	0.5	251	20.1	2.2	77.7	urb
23	01374494	Haviland Hollow Brook near Putnam Lake, NY	32	131	0.2	58	2.1*	1.0*	96.9	urb*
24	01374960	Hallocks Mill Brook at Yorktown Heights, NY	27	145	0.9	508	49.6	4.9	45.5	urb
25	01374987	Kisco River below Mount Kisco, NY	46	72	0.5	359	23.9	5.5	70.6	urb
26	01376500	Saw Mill River at Yonkers, NY	62	37	0.9	1059	60.6	1.2	38.2	urb

* Land use percentage and (or) category adjusted on basis of estimates from drive-by reconnaissance of basin.

[1] agr, agricultural; for, forested; urb, urban.

percent urban and 10 percent agricultural land cover, as determined by land use data and basin reconnaissance). Sampling reaches were selected to include riffle habitats with substrate composed primarily of cobble, gravel, and (or) boulder.

The percentages of each watershed that were agricultural, urban, and (or) forested (the latter category included other natural land covers such as wetlands) were compiled from data provided by the Multi-Resolution Land Characteristics Interagency Consortium, which used Landsat Thematic Mapper data from 1988 to 1993 (Vogelman et al., 1998). We used information gained by basin reconnaissance to adjust land use percentages in selected basins in which recent conversion of agricultural land to low-density residential land was not reflected in the land use data. In these cases, we adjusted agricultural and residential land-use percentages to more accurately reflect the actual land cover we observed by driving throughout the watershed. Watersheds were classified as agricultural or urban depending on the dominant land use; watersheds in which less than 3 percent of the area was agricultural and (or) urban were classified as forested. Population data for 1990 were obtained from the U.S. Bureau of Census.

Invertebrate sampling

One sample of benthic invertebrates was collected from each site between July 19 and August 19, 1993, during summer base flow. Samples were collected from riffles with cobble and gravel or cobble and boulder substrate by kick-sampling for 5 minutes while proceeding diagonally downstream through 5 meters of riffle (as described in Bode and Novak 1995, and Bode et al. 1996). The kick net used was 0.5 m wide and was fitted with 800 x 900 micron mesh. Samples were preserved in 75% ethanol, and processed at the NYSDEC Stream Biomonitoring Unit Laboratory in Troy, NY., by methods described in Bode et al. (1996, in accordance with methods of Hilsenhoff 1982; and Plafkin et al. 1989), in which a 100-specimen subsample was randomly picked from each sample. Each specimen was identified to species or the lowest possible taxonomic level. By using the 100-specimen subsample procedure, the same cost-effective data used for water-quality assessment is utilized for impact-source determination. Additionally, the 100-specimen subsample was considered suitable for ISD because the ISD technique does not rely on species richness or on rare taxa due to its emphasis on relative abundances (rounded to the nearest five percent) of taxa.

Chemical and habitat data collection

Water-column samples were collected during 3 different periods of base flow: (1) a summer sampling period (July through August 1993), with the lowest base flows; (2) an early-spring sampling period (late March through early April 1994), with the highest base flows;

and (3) a late-spring sampling period (June 1994), with intermediate base flows. Samples were analyzed for nutrients, organic carbon, major ions, alkalinity, pH, chlorophyll a, and pesticides (the latter two were analyzed only during the summer sampling period and late-spring sampling period, respectively). Water-column samples were collected by methods of Shelton (1994), and submitted to the USGS National Water Quality Laboratory (NWQL) in Arvada, Co., for analysis. Samples collected during the summer sampling period were also analyzed for fecal coliform concentration by methods of American Public Health Association (1985). Depth and current velocity were measured at each of 5 points in the riffle, on the same day as invertebrate sample collection. The angle of canopy closure and the width of the wetted channel were measured at 4 to 6 transects at each site. Stream-segment elevation, gradient, and sinuosity were estimated from USGS 1:24,00-scale topographic maps. Stream discharge was measured by automatic USGS gages, or by hand according to methods of Rantz (1982). More information on collection of habitat and geomorphic data can be found in Meador et al. (1993). Bed-sediment concentrations of contaminants collected at a subset of the sites during 1993-94 as part of the NAWQA program (Phillips et al. 1997) were also obtained for our analyses. These include two organochlorine pesticides that were widely detected in the study area (Phillips et al. 1997): chlordane, which was applied primarily in urban areas, and DDT, which had agricultural, urban, and forestry applications. The sum of the parent compound and its metabolites was used for our analyses. Organochlorine concentrations were not normalized to organic carbon because to do so would not markedly affect results.

ISD, multivariate, and multimetric analyses

Two invertebrate data matrices were compiled. Each consisted of relative abundances of each taxon within each sample. A full data matrix, containing all taxa identified to the lowest possible taxonomic level at each site, was compiled for calculation of metrics, indices, and ISD. A condensed and censored data matrix was compiled for use in the ordination analysis. This data matrix was prepared by (1) condensing most taxa to the lowest common taxonomic level among samples, and (2) eliminating rare taxa, which we defined as those present in fewer than 10% of samples and constituting less than 0.2 percent of the entire collection. Rare taxa are commonly eliminated prior to multivariate analysis because (1) their occurrence in a sample might be due more to chance than to ecological conditions, and (2) they can appear as outliers in ordination analyses (Gauch 1982).

ISD classifications were determined on the basis of similarity (Whittaker and Fairbanks 1958; Whittaker 1975) of relative abundances for selected taxa in each sample to those in each ISD model community (Appendix I), according to Bode et al. 1996. Each site was given the impact class of the model community to which its sample was most similar. According to the ISD procedure, multiple classifications were given if percent similarities of several highest models were within 5 percentage points of each other. An exception is the "impoundment" source class, which is only intended to apply to sites downstream of impoundments or sluggish conditions, so as not to classify a site as "nutrient" impaired when it is actually impaired by the upstream impoundment. Because we purposefully selected sites to avoid impoundments, we did not utilize this classification option.

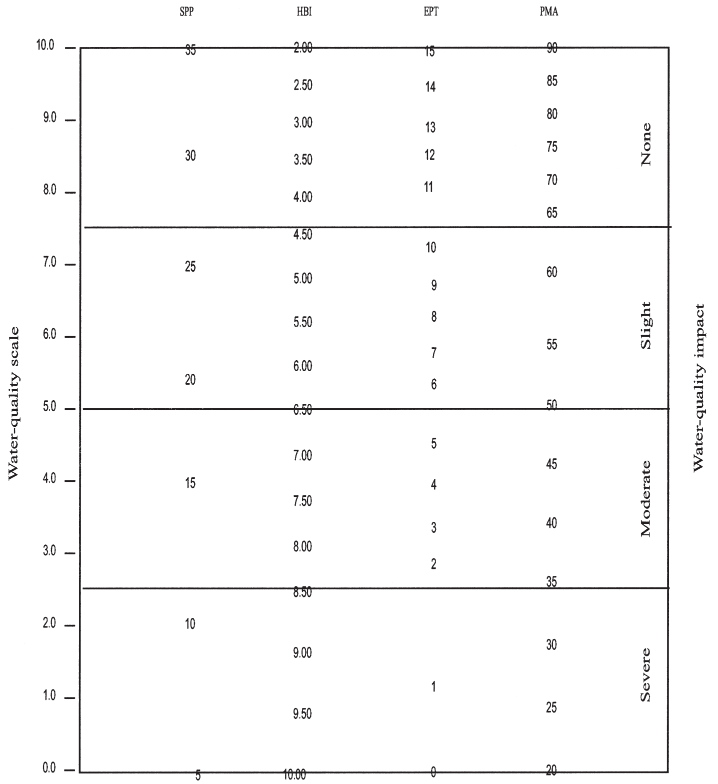


Figure 2. Biological Assessment Profile of index values for riffle habitats, from New York State Department of Environmental Conservation (Bode et al. 1996). Spp = species richness, HBI = Hilsenhoff Biotic Index, EPT = Ephemeroptera, Plecoptera, Trichoptera richness, PMA = Percent Model Affinity. Values from the 4 indices are converted to a common scale and the mean of the four scaled index values is the final assessment value.

The degree of impairment was assessed by calculating several widely-used macroinvertebrate metrics and indices, as well as a multimetric index developed by NYSDEC and used in their biomonitoring throughout the State. EPT richness and Hilsenhoff's Biotic Index (HBI, Hilsenhoff 1987) are commonly employed in biomonitoring. The Biological Assessment Profile is a multimetric index that is used for biomonitoring and assessment throughout the State. The Biological Assessment Profile integrates results of total richness, EPT richness, HBI, and Percent Model Affinity (Novak and Bode, 1992) by scaling each to a 10-point range, and taking the mean (Fig. 2, Bode et al. 1996). Classification of taxa as to tolerance levels followed Bode et al. (1996), Hilsenhoff (1987), Merritt and Cummins (1996), and Pennak (1989).

Canonical Correspondence Analysis (CCA) was used to summarize variation in benthic macroinvertebrate communities and to relate this variation to environmental gradients. CCA is a form of canonical ordination, which relates species composition directly to environmental conditions. CCA constrains the variation in the species data set so that it is expressed as linear combinations of the environmental variables (ter Braak and Smilauer 1998). The axes, or eigenvectors, that are produced are uncorrelated with each other. Those explaining a relatively high percentage of the variation in the species and environment correlation can be interpreted as independent environmental gradients. Ordination triplots of site scores, environmental variables, and species scores show samples having similar invertebrate composition and relative abundance as points located close to each other and those with different communities as points located farther apart. Each environmental variable is represented by an arrow pointing in the direction of increasing value (and, although not shown on the biplots, extending an equal amount in the opposite direction). The acuteness of the angle between the arrow and an ordination axis corresponds with the strength of their correlation, and the length of each arrow represents the environmental variable's relative importance to the analysis. Species locations in these plots represent the weighted averages of species relative abundances with respect to the environmental variables.

Environmental variables were assessed to select, for CCA, a small subset that captured much of the variation among sites. The original suite of variables required reduction because of the many water-column constituents determined for each of the 3 sampling periods (resulting in more than 100 water-column variables alone). The number of variables retained for the analysis was first reduced by inspection of correlation matrices (Spearman rank correlation analysis; Sokal and Rohlf 1995) and elimination of variables that were highly correlated with others. Other variables were eliminated because they exhibited little variance, had highly skewed distributions even after transformation, had missing variables for several sites, or were likely to exhibit high diel variability. The selected variables were transformed with log or square root transformation to improve normality, where this was indicated as necessary by graphical examination of the distribution and by Kolmogorov-Smironov tests (Sokol and Rohlf 1995). Principal components analysis (PCA, not shown here) was then used to make the final selection of environmental variables for use in CCA; variables with low loadings (i.e., correlations) on the major PCA axes were considered to contribute relatively little to environmental variation among samples and were eliminated from further consideration. Missing values for late summer concentrations of total nitrogen, fecal coliform, and chlorophyll-a (each missing at a single unique site) were replaced, prior to PCA and CCA, by substituting median concentration (total nitrogen), or by regression (fecal coliform concentration with summer chloride concentration; chlorophyll-a concentration with late-spring total nitrogen concentration).

Because of the potential effect of stream size on invertebrate communities, we considered including drainage area as a covariable in a partial CCA (ter Braak and Prentice 1988). However, PCA results indicated that stream size was not an important source of variation relative to other variables, and site scores from an earlier detrended correspondence analysis of macroinvertebrate relative abundances (not shown) were not significantly correlated with drainage area or other variables associated with stream size. Thus, we determined that stream size had been sufficiently restricted in our site selection process, and that it was not necessary to include drainage area as a covariable in the CCA.

Variation among samples in benthic invertebrate communities as they relate to the identified environmental gradients of interest was then examined by use of CCA, which was performed on macroinvertebrate relative abundances with no down weighting of rare taxa (ter Braak and Smilauer 1998). The most severely-impacted urban site (site 11) exerted undue influence in earlier detrended correspondence analyses (not shown), and was, therefore, given lower weight (0.01) in the CCA to reduce its influence on the ordination (ter Braak and Smilauer 1998). Spearman rank correlation analysis was used to examine relations between site scores on CCA axes and selected basin characteristics, habitat variables, and water-column constituents that were not explicitly included in the CCA. Site classifications, according to ISD, were compared with environmental gradients identified in CCA by examining their positions on the ordination plots.

RESULTS

The total number of taxa collected was 158, and consisted of 7 insect orders and 7 noninsect classes. A list of benthic macroinvertebrate taxa collected, and the overall frequency of occurrence and abundance of each is provided in Appendix II; the complete data set with abundances for each sample is reported in Butch et al. (1998). Removal of rare taxa and condensation to the lowest common taxonomic level left a total of 77 taxa in the data set used for CCA.

Impact Source Determination results

Most sites were impaired by nonpoint nutrients, according to ISD, which classified 7 sites as "nonpoint nutrient," 5 as "nonpoint nutrient and natural," and 5 as a mixed classification of "nonpoint nutrient," and one or more of the other impact classes (Table 3). Four sites were classified as "complex," 2 as "siltation," and 3 as "natural." Most ISD classifications corresponded with watershed land use with the potential for the particular impact source. Sites classified as "complex" were all highly urban, in primarily older cities. Sites classified as "natural" and those classified as "natural and nonpoint" were in primarily forested watersheds with low percentages of agricultural or urban land. Siltation-impaired sites, each classified as "siltation," "siltation and nonpoint nutrient," or "siltation, nonpoint nutrient, and natural" were in watersheds with moderate to high percentages of agricultural land.

Table 3. Biological Assessment Profile and Impact Source Determination (ISD) results based on benthic macroinvertebrate biomonitoring data. Samples were collected from streams in the Hudson River Basin (New York, U.S.A.) during 1993.

	Biological Assessment		Impact Source Determination					
Site #	Rating	Class	Natural	Nutrient	Toxic	Organic	Complex	Siltation
1	8.06	nonimpacted	52	**58**	25	39	31	50
2	6.05	slight	50	**73**	51	54	37	64
3	6.12	slight	**74**	32	25	57	25	37
4	5.05	slight	36	44	44	47	31	**56**
5	7.62	nonimpacted	**66**	**69**	45	52	39	55
6	6.91	slight	37	**68**	40	39	35	41
7	6.24	slight	38	**57**	51	49	**58**	**57**
8	7.62	slight	**46**	**43**	30	29	16	36
9	6.41	slight	50	**54**	47	50	35	**58**
10	5.81	slight	30	**43**	37	**40**	39	**43**
11	1.41	severe	17	17	38	52	**88**	30
12	7.07	slight	43	33	33	40	27	**52**
13	6.36	slight	**61**	**60**	34	51	44	**56**
14	6.88	slight	**69**	34	22	57	27	25
15	6.43	slight	45	**68**	52	61	**66**	53
16	7.85	nonimpacted	**49**	**49**	39	38	35	43
17	7.87	nonimpacted	**53**	41	29	31	19	34
18	4.84	moderate	31	47	36	47	**59**	49
19	6.89	slight	47	**80**	42	59	57	51
20	5.96	slight	50	**59**	40	51	47	47
21	6.61	slight	35	**45**	40	30	29	38
22	7.53	nonimpacted	45	**65**	46	55	54	56
23	6.55	slight	**45**	**46**	36	25	27	33
24	6.19	slight	34	43	41	36	**52**	38
25	6.92	slight	**53**	**55**	34	43	42	46
26	2.82	moderate	21	21	52	54	**84**	32

Metric and index results

Water quality impairment, according to Biological Assessment Profile results (Table 3), ranged from severe at one urban site (site 11), classified as "complex" by ISD, to nonimpaired at several forested, urban, and agricultural sites classified as "natural" (Site 17), "nonpoint nutrients" (sites 1 and 22), or a combination of the two (sites 5 and 16). Most sites were slightly impacted. This slight impairment had a variety of sources, according to ISD. Slightly-impacted sites included agricultural, urban, and forested sites with "nonpoint nutrient" classifications, "siltation" classifications, and mixed classifications, as well as a forested sites with a "nonpoint nutrient and natural" classification and an urban site with a "complex" classification (Table 3). In general, water-quality impairment, as assessed by Biological Assessment Profile, was related to percentage of disturbed land in the watershed. Biological Assessment Profile score was positively correlated with percentage of forested land (Spearman rho 0.67, $p = 0.0001$) and negatively correlated with population density (Spearman rho -0.52, $p = 0.005$) and percentage of urban land in the watershed (Spearman rho -0.47, $p = 0.013$). The relation between water quality and land use was also maintained upon separation of agricultural and urban site groups. Within the agricultural group ($n = 14$), Biological Assessment Profile was positively correlated with the watershed's percentage of forested land (Spearman rho 0.66, $p = 0.01$), and negatively correlated with the watershed's percentage of agricultural land (Spearman rho -0.63, $p = 0.016$). Within the urban group ($n = 10$), Biological Assessment Profile was positively correlated with the watershed's percentage of forested land (Spearman rho 0.76, $p = 0.01$) and negatively correlated with its population density and percentage of urban land (Spearman rho -0.67 and -0.68, respectively; $p = 0.03$ and 0.01, respectively). ISD and Biological Assessment Profile rating appeared to be in disagreement for 2 sites that had a water quality rating of slightly impacted but an ISD classification of "natural." Both sites were characterized by high relative abundances of *Micropsectra* spp. (Diptera: Chironomidae).

Environmental variables

Seven environmental variables were selected for CCA: specific conductance, chloride concentration, and fecal coliform concentration from the summer sampling period; total nitrogen concentration from the late-spring sampling period; and suspended organic carbon and total nitrogen concentrations from the early spring sampling period. Chloride, fecal coliform, suspended organic carbon, and suspended sediment concentrations were log transformed prior to CCA; specific conductance and the 2 total nitrogen variables were square-root transformed. Summary statistics for the seven selected environmental variables and selected other chemical and physical variables are provided in Table 4.

Table 4. Summary statistics for selected biological indices, environmental variables, and watershed characteristics. Number of samples = 26 unless specified differently in parentheses. (Min = miminum, max = maximum, N = nitrogen, EPT = Ephemeroptera, Plecoptera, and Trichoptera, ww = wet weight, nd = not detected).

Variable	Median	Min-Max
Water column constituents, summer sampling period		
Alkalinity, mg/l	113	6-191
Ammonia, mg/l as N (25)	0.03	<0.01-0.50
Ammonia + total organic N, mg/l as N (25)	<0.20	<0.20-1.2
Chloride, mg/l	19	1.5-130
Chlorophyll A, phytoplankton, mg/l (25)	0.90	0.20-15
Fecal coliform, colonies/100ml (25)	154	4-14,330
Orthophosphate, mg/l (25)	<0.01	<0.01-0.12
Specific conductance, μs/cm	340	26.8-1164
Sulfate, mg/l	18	4.1-550
Suspended organic carbon, mg/l	0.1	<0.1-1.4
Water column constituents, early-spring period		
Ammonia + total organic N, mg/l as N	<0.20	<0.20-1.5
Chloride, mg/l	9.8	1.3-190
Dissolved organic carbon, mg/l	2.35	1.0-5.6
Specific conductance, μs/cm	202	21.8-1050
Sulfate, mg/l	12.5	5.1-67
Suspended organic carbon, mg/l	0.30	0.10-1.6
Suspended sediment, mg/l	7	1-113
Total nitrogen, mg/l	0.72	0.20-2.24
Water column constituents, late spring sampling period		
Alkalinity, mg/l	99	2-184
Ammonia, mg/l as N	0.03	<0.02-0.43
Ammonia + total organic N, mg/l as N	<0.20	<0.20-1.20
Chloride, mg/l	15.0	1.0-180
Dissolved organic carbon, mg/l	2.6	1.1-5.4
Nitrite + nitrate, dissolved, mg/l as N	0.37	<0.05-0.94
Orthophosphate, mg/l	<0.01	<0.01-0.04
Specific conductance μs/cm	330	23.9-1229
Sulfate, mg/l	14	4.9-550
Total nitrogen, mg/l	0.59	<0.05-1.99
Total pesticide concentration[1], mg/l	0.03	nd-1.75
Macroinvertebrate indices and metrics		
Biological Assessment Profile	6.49	1.41-8.06
EPT richness	8.5	0-13
Hilsenhoff's Biotic Index	5.04	2.96-9.29
Percent Model Affinity	56.5	28-72
Percent abundance as collector-filterers	28	0-72
Percent abundance as collector-gatherers	19	6-80
Percent abundance as scrapers	23	2-47
Percent abundance as shredders	5	0-44
Geomorphic and habitat characteristics		
Canopy closure angle, degrees	135	0.2-3.5
Gradient of stream segment, m/km	0.7	28-192
Sinuosity of stream segment	1.4	1.0-2.0
Percentage of reach as riffle	31	14-76
Wetted width (m)	9.7	3.5-32.0
Water temperature pre-dawn[2], degrees C (25)	19	13.5-21
Bed sediment contaminants		
Cadmium, μg/g (20)	0.70	0.20-6.90
Total chlordane compounds, μg/kg dw (21)	<1.0	<1.0-56.8
Total DDT compounds, μg/kg dw(21)	2.4	<1.0-48
Total polychlorinated biphenyls, μg/kg dw (22)	<50	<50-290

[1] Sum of pesticides and metabolites, [2] Measured on chemistry sampling data, summer sampling period.

Original values for chemical concentrations and stream-discharge measurements are reported for each site in Firda et al. (1993, 1994).

Canonical Correspondence Analysis results

The first 3 CCA axes (eigenvectors) accounted for 61 percent of the variance in the species-environment relation. Eigenvalues, which represent the contribution of each axis to the ordination (Gauch, 1982) were 0.49, 0.37, and 0.29 for Axes I, II, and III, respectively. Results of Monte Carlo tests of the significance of the first axis and all CCA axes ($p = 0.007$ and 0.005, respectively), indicated a significant relation between the macroinvertebrate relative abundances and the selected environmental variables. Table 5 provides intraset correlations between eigenvectors and each of the seven environmental variables used in the CCA.

Sites classified as "complex" and sites classified as "natural" were in opposite ends of Axis I (Fig. 3, Table 6); sites classified as "nonpoint nutrient," "silt," and others occupied intermediate positions along Axis I. This gradient contrasts forested, low-urban, and low-agricultural sites supporting sensitive taxa such as mayflies, caddisflies, and riffle beetles, with highly urban sites characterized by worms, scuds, and tolerant midge species (Fig. 3). The importance of fecal coliform to Axis I (Table 5) suggests a gradient in constituents associated with municipal sewage, industrial sources, and urban runoff, as well as septic, and (or) animal sources. This is supported by significant correlations between Axis I site scores and concentrations of sulfate, nutrients, and ammonia, especially those input during the low base-flow conditions of summer, as well as a significant positive correlation with cadmium, chlordane, and polychlorinated biphenyl concentrations in bed sediments and with water-column pesticide concentrations (Table 7). Significant negative correlations with Biological Assessment Profile, Percent Model Affinity, and EPT indicate increasing water-quality impairment; a significant positive correlation with HBI indicates that organic enrichment is an important feature of this impairment. Wide separation of certain congeners was noted along this disturbance gradient (Fig. 3, Table 6). For example, *Polypedilum aviceps*

Table 5. Canonical correlations (r^2) for the seven environmental variables used in Canonical Correspondence Analysis. Eigenvalues for each axis are given in parentheses. Correlations significant at $p < = 0.05$ are in bold.

		Canonical correlations		
Sampling period	Environmental variable	Axis I (0.494)	Axis II (0.367)	Axis III (0.294
Summer	Chloride	0.73	-0.21	**-0.34**
	Fecal coliform	**0.88**	**0.03**	-0.13
	Specific conductance	0.67	**-0.19**	0.01
Early spring	Suspended organic carbon	**0.14**	**0.27**	**0.77**
	Suspended sediment	0.03	**0.11**	**0.81**
	Total nitrogen	0.36	**0.13**	0.26
Late spring	Total nitrogen	0.49	**-0.49**	**0.10**

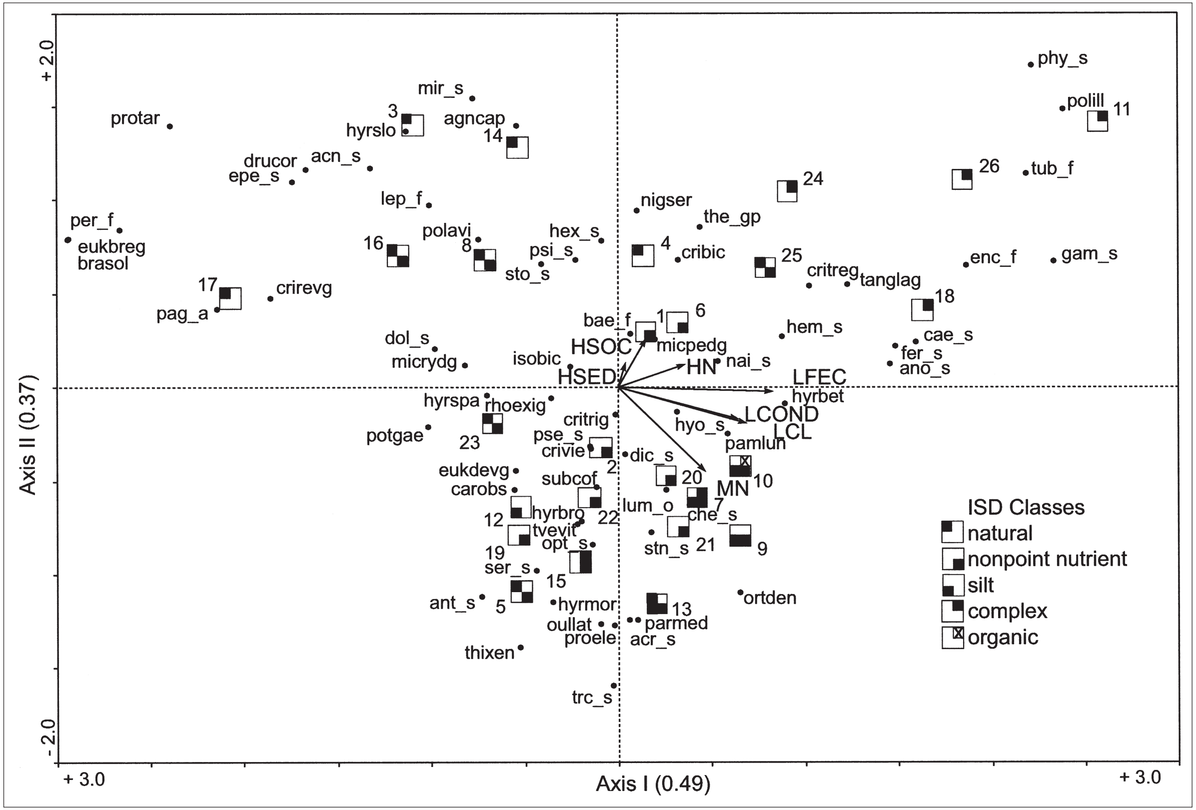


Figure 3. Plot of taxa scores, site scores, and environmental variables on Axes I and II from Canonical Correspondence Analysis of benthic macroinvertebrate relative abundances. Samples were collected from 26 sites in the Hudson River Basin during 1993. Eigenvalues are given in parentheses. Some taxa have been removed for clarity. Site numbers correspond with site names listed in Table 2. Taxa names corresponding with abbreviations shown are listed in Table 6. ISD = Impact Source Determination. HSED = sediment concentration, early spring sampling period. HSOC = suspended organic carbon concentration, early-spring sampling period. HN = total nitrogen concentration, early spring sampling period. MN = total nitrogen concentration, late spring sampling period. LCL = chloride concentration, summer sampling period. LCOND = specific conductance, summer sampling period. LFEC = fecal coliform concentration, summer sampling period.

(Diptera: Chironomidae), *Hydropsyche slossonae* and *H. sparna* (Trichoptera: Hydropsychidae), and *Cricotopus reversus* gr. (Diptera: Chironomidae) were associated with the cleaner streams along Axis I, whereas *P. illinoense*, *H. betteni*, and *C. tremulus* gr. were associated with higher pollution according to position along Axis I. Axis I was positively correlated with population density and percentage of urban land in the watershed, and negatively correlated with percentage of forested land in the watershed (Table 7). The only natural landscape or habitat features with which Axis I site scores had significant ($p < 0.05$)

Table 6. List of abbreviations and corresponding taxa shown in Canonical Correspondence Analysis triplots (Figures 3 and 4).

Abbrev.	Taxon	Abbrev.	Taxon
acn_s	*Acentrella* sp.	isobic	*Isonychia bicolor*
acr_s	*Acroneuria* sp.	lep_f	Leptophlebiidae
agncap	*Agnetina capitata*	lum_o	Lumbricina
ano_s	*Anthopotamus* sp.	micpedg	*Microtendipes pedellus* gr.
ant_s	*Antocha* sp.	micrydg	*Microtendipes rydalensis* gr.
ath_s	*Atherix* sp.	mir_s	*Micropsectra* sp.
bae_f	Baetidae	nai_s	*Nais* sp.
bat_s	*Baetis* sp.	nigser	*Nigronia serricornis*
brasol	*Brachycentrus solomoni*	opt_s	*Optioservus* sp.
cae_s	*Caecidotea* sp.	ortden	*Orthocladius* nr. *dentifer*
can_s	*Caenis* sp.	oullat	*Oulimnius latiusculus*
carobs	*Cardiocladius obscurus*	pag_a	*Pagastia* sp. A
che_s	*Cheumatopsyche* sp.	pamlun	*Parametriocnemus lundbecki*
chi_s	*Chimarra* sp.	parmed	*Paragnetina media*
cribic	*Cricotopus bicinctus*	per_f	Perlidae
crirevg	*Cricotopus reversus* gr.	phy_s	*Physella* sp.
critreg	*Cricotopus tremulus* gr.	polavi	*Polypedilum aviceps*
critrig	*Cricotopus trifascia* gr.	polfla	*Polypedilum flavum*
crivie	*Cricotopus vierriensis*	polill	*Polypedilum illinoense*
dia_s	*Diamesa* sp.	potgae	*Potthastia gaedii*
dic_s	*Dicranota* sp.	proele	*Promoresia elegans*
dol_s	*Dolophilodes* sp.	protar	*Promoresia tardella*
drucor	*Drunella cornutella*	prtgra	*Prostoma graecense*
enc_f	Enchytraeidae	pse_s	*Psephenus* sp.
epe_s	*Epeorus* sp.	rherob	*Rheocricotopus robacki*
eukbreg	*Eukiefferiella brehmi* gr.	rhoexig	*Rheotanytarsus exiguus* gr.
eukdevg	*Eukiefferiella devonica* gr.	ser_s	*Serratella* sp.
fer_s	*Ferrissia* sp.	stn_s	*Stenelmis* sp.
gam_s	*Gammarus* sp.	sto_s	*Stenonema* sp.
hem_s	*Hemerodromia* sp.	subcof	*Sublettea coffmani*
hex_s	*Hexatoma* sp.	tanglag	*Tanytarsus glabrescens* gr.
hyo_s	*Hydroptila* sp.	the_gp	*Thienemannimyia* gr. spp.
hyr_s	*Hydropsyche* sp.	thixen	*Thienemanniella xena*?
hyrbet	*Hydropsyche betteni*	trc_s	*Tricorythodes* sp.
hyrbro	*Hydropsyche bronta*	tub_f	Tubificidae
hyrmor	*Hydropsyche morosa*	tvebavg	*Tvetenia bavarica* gr.
hyrslo	*Hydropsyche slossonae*	tvevit	*Tvetenia vitracies*
hyrspa	*Hydropsyche sparna*		

Table 7. Spearman rank correlations between selected variables and the first three axes from Canonical Correspondence Analysis (CCA). Eigenvalues for each axis are given in parentheses. Only variables having one or more correlations greater than 0.50 are shown. Number of samples = 26 unless specified differently in parentheses. * $p < = 0.05$, ** $p < = 0.01$, *** $p < = 0.001$, ns $p > 0.05$.

Environmental variable	Axis I (0.494)	Axis II (0.367)	Axis III (0.294)
Water column constituents, summer sampling period			
Alkalinity	0.68***	ns	ns
Ammonia (25)	0.56**	ns	-0.44*
Ammonia + total organic nitrogen (25)	0.71***	ns	ns
Chlorophyll A (25)	0.61**	ns	ns
Orthophosphate(25)	0.40*	ns	-0.58**
Sulfate	0.73***	ns	ns
Suspended organic carbon	0.55**	ns	ns
Total nitrogen (25)	0.56**	ns	-0.50**
Water column constituents, early-spring sampling period			
Ammonia + total organic nitrogen	0.56**	ns	ns
Chloride	0.64***	ns	-0.41*
Dissolved organic carbon	0.56**	ns	ns
Specific conductance	0.84***	ns	ns
Sulfate	0.80***	ns	ns
Water column constituents, late-spring sampling period			
Alkalinity	0.76***	ns	ns
Ammonia	0.81***	ns	ns
Chloride	0.66***	ns	ns
Dissolved organic carbon	0.60**	ns	ns
Orthophosphate	0.51**	ns	ns
Specific conductance	0.85***	ns	ns
Sulfate	0.77***	ns	ns
Total water-column pesticides	0.53**	ns	ns
Watershed characteristics			
Percent total area as forested land	-0.87***	ns	ns
Percent total area as agricultural land	ns	-0.41*	0.60***
Percent total area as urban land	0.67***	ns	-0.40*
Population density	0.66***	ns	-0.44*
Geomorphic and habitat characteristics			
Elevation	-0.59**	ns	ns
Sinuosity	0.59**	ns	ns
Canopy closure angle	ns	ns	-0.75***
Minimum water temperature^1	0.51**	ns	ns
Bed sediment contaminant concentrations			
Cadmium (n=20)	0.50**	ns	ns
Total chlordane compounds (n=21)	0.51*	ns	-0.52*
Total DDT compounds (n=21)	ns	ns	-0.61*
Total polychlorinated biphenyls (n=22)	0.58**	0.51	ns**
Macroinvertebrate indices and metrics			
Biological Assessment Profile	-0.69***	ns	ns
EPT^2 richness	-0.66***	ns	ns
Hilsenhoff's Biotic Index	0.65***	ns	0.38*
Percent Model Affinity	-0.51**	ns	ns
Percent abundance as CF + SCR^3	ns	-0.67***	ns
Percent abundance as CG + SHR^4	ns	0.63**	ns

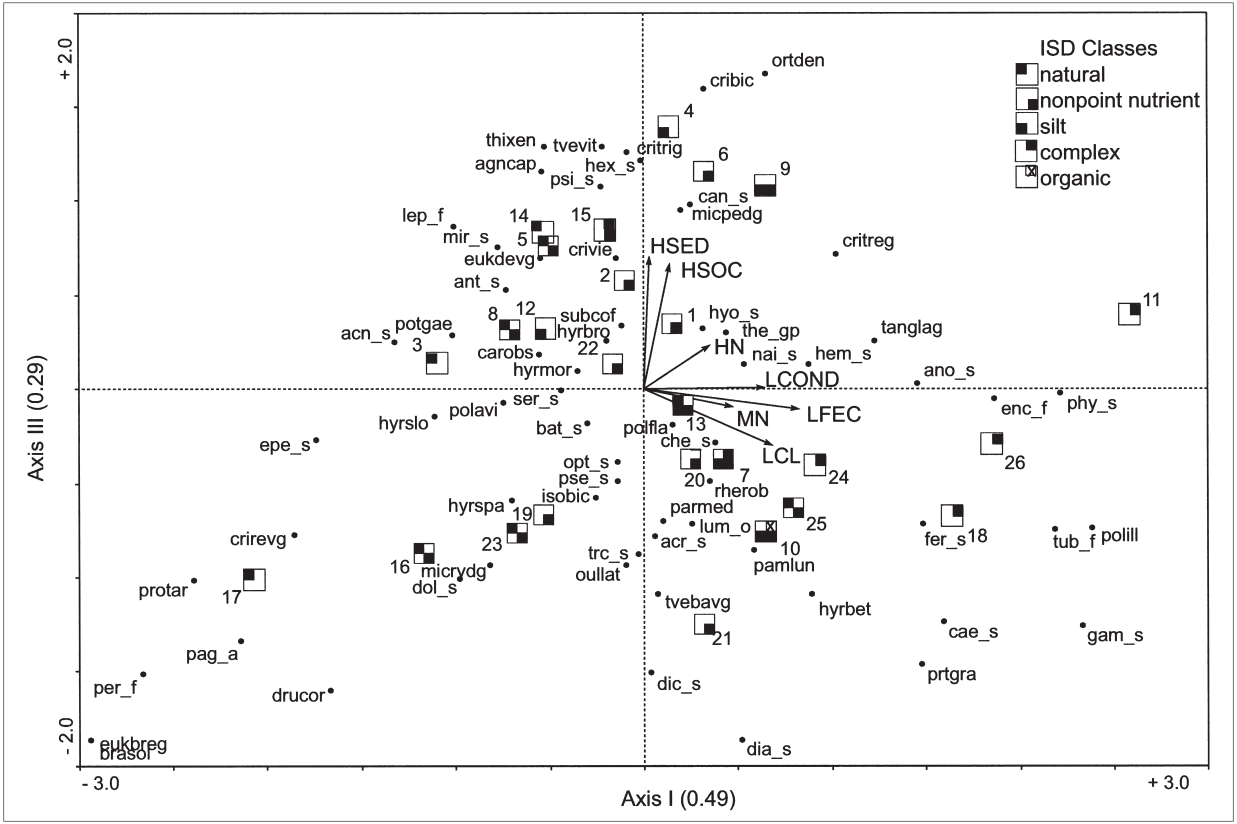
[1] Pre-dawn temperature on date of summer sample collection; [2] Ephemeroptera, Plecoptera, and Trichoptera; [3] Collector-filterers plus scrapers; [4] Collector-gatherers plus shredders.

correlations greater than 0.50 were elevation, which was negatively correlated, and sinuosity, which was positively correlated. Discharge per unit area (for any sampling period), percent of pools, riffles, and runs, and gradient, drainage area, and depth, width, and velocity were not significantly correlated (at rho = 0.50 or greater) with site scores along this axis. Sites in the Northeastern Highlands ecoregion were more likely to have lower scores on Axis I than either of the two other ecoregions (Tukey's studentized range test on ranked data, $p < 0.01$). This appears to be largely accounted by the significantly greater proportion of forested land cover in Northeastern Highlands ecoregion watersheds than those in the other two ecoregions, and in the significantly greater proportion of agricultural land in Eastern Great Lakes and Hudson Lowlands watersheds than in watersheds in the Northeastern Highlands or in the New England Coastal Plain ecoregions (Tukey's studentized range test on ranked data, $p < 0.0001$).

Most sites classified as "nonpoint nutrient" (either singly or in combination with other classifications) were separated from those classified as "natural" and those classified as "complex" along Axis II (Fig. 3). Late spring total nitrogen was the most influential variable to this axis (Table 5), followed by early spring suspended organic carbon. Late spring total nitrogen was highly correlated with late spring dissolved nitrite plus nitrate (Spearman rho = 0.87, $p < 0.0001$), suggesting an underlying gradient associated with dissolved nutrients from shallow groundwater. Nutrient enrichment is also indicated by the significant correlation between Axis II site scores and percent collector-filterers plus scrapers (Table 7). The orientation of both urban and agricultural sites in the higher-nutrient zone of this axis suggests either a similar nutrient (and related constituents) source in these agricultural and urban watersheds, or similar community responses to fertilizers applied to agricultural and urban lands. Site scores exhibited no significant correlation with variables related to discharge per unit area, stream size, elevation, or channel shape, and there was no statistically significant difference in site scores among ecoregions (Tukey's studentized range test on ranked data, $p > 0.05$). Finally, site scores along this axis were not significantly correlated with any of the macroinvertebrate water-quality indices; this is likely due to the separation of the nonpoint nutrient impacted sites from both "natural" sites and "complex" sites.

Axis III is associated primarily with increasing concentrations of early spring sediment and suspended organic carbon, such as would be contributed by overland runoff (Table 5, Fig. 4). Site scores on this axis were positively correlated with proportion of agricultural land in the watershed, and were negatively correlated with canopy closure (Table 7), suggesting a role of streambank and riparian disturbance associated with agricultural land practices. Axis III separated agricultural sites from forested sites, which would have more intact riparian zones, and from urban sites, which would have more impervious surface and thus provide

Figure 4. Plot of taxa scores, site scores, and environmental variables on Axes I and III from Canonical Correspondence Analysis of benthic macroinvertebrate relative abundances. Samples were collected from 26 sites in the Hudson River Basin during 1993. Eigenvalues are given in parentheses. Some taxa have been removed for clarity. Site numbers correspond with site names listed in Table 2. Taxa names corresponding with abbreviations shown are listed in Table 6. ISD = Impact Source Determination. HSED = sediment concentration, early spring sampling period. HSOC = suspended organic carbon concentration, early spring sampling period. HN = total nitrogen concentration, early spring sampling period. MN = total nitrogen concentration, late spring sampling period. LCL = chloride concentration, summer sampling period. LCOND = specific conductance, summer sampling period. LFEC = fecal coliform concentration, summer sampling period.



a lower sediment source. Both of the sites with "siltation" ISD classifications (sites 4 and 12), and the site with combined "siltation" and "nonpoint-nutrient" classifications (site 9) were located in the higher overland runoff portion of Axis III. Site 13, with combined classifications of "siltation," "nonpoint nutrient," and "natural" was located near the middle range of Axis III. Taxa associated with the higher runoff section of the gradient included *Caenis* sp. (Ephemeroptera: Caenidae), *Cricotopus bicinctus, C. trifascia* gr.*, C. vierriensis, C. tremulus* gr., *Eukiefferiella devonica* gr. (Diptera: Chironomidae), and *Tvetenia vitracies* (Diptera: Chironomidae). Those associated with the lower runoff portion of the gradient include *Cricotopus reversus* gr., *E. brehmi* gr., and *T. bavarica* gr. Several *Hydropsyche* congeners were also widely separated along this axis. *Hydropsyche bronta* and *H. morosa* were nearer the high runoff end of the axis than were *H. sparna*, and *H. betteni*. Other environmental variables having significant correlations with Axis III were bed sediment concentrations of total chlordane and total DDT, which were negatively correlated with site scores. Axis III scores did not differ significantly among ecoregions (Tukey's studentized range test, $p > 0.05$).

ISD classifications for two sites appeared to be in disagreement with their ordination positions. Site 25 was classified as "nonpoint nutrient and natural," yet was located near "complex" sites and the higher-pollution end of Axis 1. This site had relatively high fecal coliform concentrations, and was downstream of organically enriched sites (RW Bode, NYSDEC, personal communication). Site 6 was classified as "nonpoint-nutrient," but was located in a very low position on the nutrient axis (Fig. 3), and a relatively high position on the runoff axis (Fig. 4).

DISCUSSION

ISD classifications for most sites compared favorably with position along environmental gradients produced by CCA. Several ISD groups were clearly distinguished in the ordination plots, particularly "complex," "natural," and "nonpoint nutrient" (including combinations of "nonpoint nutrient" and other impairment classes), which were separated in the plot of Axes I and II (Fig. 3). Most sites classified as "siltation" were distinguished from "natural" sites and from "complex" sites along Axis III (Fig. 4).

The dominant environmental gradient along which sites varied (i.e., Axis I) can be interpreted as an overall pollution gradient that includes organic enrichment and toxic constituents from point and nonpoint sources. This environmental gradient progresses from forested sites with good water quality to highly urban sites with poor water quality. The importance of constituents such as fecal coliform, ammonia, and sulfate collected during periods of lower base flows, and the correlation with concentrations of contaminants in streambed sediment samples, suggest sources including municipal and industrial sewage, urban runoff, and possibly including septic effluent and animal waste sources. This corresponds with the location of the "complex" sites because this ISD classification includes both organic enrichment and toxic components. Three of 4 sites designated as "complex" and affected by municipal/industrial discharges had the worst water quality, according to Biological Assessment Profile ratings (Table 3). Most sites affected by nonpoint sources of nutrients and (or) siltation were in intermediate locations along this gradient, corresponding with their Biological Assessment Profile rating of "slightly impaired."

A negative correlation between Axis I and Hilsenhoff's Biotic Index, and especially the importance of fecal coliform, suggests that organic enrichment is an important feature of the underlying environmental gradient, even though we avoided sites known to have sewage discharges. Many urban areas may have undocumented sewage inputs, often from leaks in the sewage collection system. Subsequent to the collection of samples in this study, site 11 was found to receive raw sewage from a construction diversion pipe that was discharging raw sewage into the creek (Bode et al. 1995); the pipe was capped after the discovery, and recent bioassessments indicate markedly improved water quality (R.W. Bode, personal communication). Leaking septic fields and animal wastes are other sources of fecal coliform. Other environmental factors that were not directly included as environmental variables in the ordination analysis may contribute to the general human disturbance gradient; these include modern pesticides, metals, organochlorine compounds, and other contaminants from current and (or) historical sources, habitat impairment, and hydrologic changes. Dominance of Tubificidae and Chironomidae has been associated in other studies with elevated concentrations of metals in bed sediments (Winner et al. 1980). Indeed, bed sediment concentrations at the 3 most highly impaired sites in our study that were classified as "complex" by ISD, and exceeded State guidelines for protection of aquatic life for lead, cadmium, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, and (or) chlordane in bed sediments (Phillips et al. 1997, Wall et al. 1998). Yoder and Rankin (1995) found *Cricotopus* sp. to be associated with a "Complex Toxic" type of community. Our results agree, but suggest that certain *Cricotopus* species might be better indicators of these conditions than others. *C. tremulus* group was nearer some of the "complex" sites along the pollution gradient than *C. reversus* group, for example. Eagleston et al. (1990) found that *Polypedilum illinoense, C. bicinctus,* and *C. vierriensis,* among others, were associated with toxic conditions in his study. Our findings agree for some of these; we found *P. illinoense* especially tolerant, according to its position on the pollution gradient, whereas *C. bicinctus* and *C. vierriensis* were more intermediate in tolerance for the range of conditions contained in our study. These findings suggest that some relatively tolerant taxa would be better indicators of complex (municipal/industrial) impact sources than others.

The second most important environmental gradient, according to CCA results, is associated with nonpoint sources of nutrients. These are associated with inorganic nutrients in late spring samples, probably entering streams from shallow groundwater. These factors are consistent with nonpoint sources such as septic fields, residential lawn fertilizers, and agricultural fertilizers. Macroinvertebrate communities from urban and agricultural sites responded similarly to variation along this nonpoint nutrient gradient. Our findings of a significant correlation between site scores on this axis and relative abundance of filterer and scraper macroinvertebrates supports an interpretation of nutrient enrichment and associated increase in primary production. Some of the taxa located in the higher nutrient zone of this axis (Fig. 3) were also suggested by Eagleston et al. (1990) to be indicative of high periphyton and FPOM; these include Hydropsychidae and *Rheotanytarsus* (Diptera: Chironomidae) species.

Sediment may be an important source of impairment to agricultural streams, as indicated by Axis III in the CCA plot (Fig. 4). Sediment impacts include lower-than-expected abundance of net-spinning caddisflies, and higher-than-expected abundance of dipteran taxa. Relatively high abundance of Chironomidae, low abundance of net-spinning filter feeders, and relatively high abundance of the silt-tolerant mayfly *Caenis* sp., indicate a possible response to suspended and (or) redeposited sediment. Suspended sediment can cause increased drift as a result of increased turbidity (Gammon 1970) and physical disturbance (Culp et al. 1986; Waters, 1995); redeposition can clog caddisfly nets and decrease interstitial space and dissolved oxygen in stream-bottom habitats (reviewed in Waters 1995). Elevated concentrations of suspended sediment have also been reported to cause a reduction in abundance of filter feeders (reviewed in Waters 1995). Sites at the higher runoff end of Axis III had some degree of obvious bank erosion, disruption of riparian vegetation, and (or) narrow riparian buffer zones, either in the immediate vicinity of the study reach or within a short distance upstream in the watershed. The negative correlation of Axis III with canopy closure supports the interpretation of this axis as a land disturbance-runoff gradient, because riparian buffer zones would mitigate effects of land disturbance.

Apparent disagreement between ISD and ordination or water-quality assessment for four sites may be due to several different factors. Site 25 appeared to be an example of a site at which groundwater inputs mitigate the effects of organic enrichment. The site had relatively high fecal coliform concentrations, which forced its position in the ordination closer to some of the “complex” sites, and which corresponds with findings of NYSDEC, for upstream sites on this river, of impairment due to organic enrichment (Bode et al. 1999). However, Site 25 was characterized by high diversity and relative abundances of mayflies, which explains the "natural and nonpoint source" ISD. The continued presence of relatively high coliform concentrations at Site 25 suggests the presence of mayflies is not simply due to recovery associated with sufficient distance from the impairment source. Instead, cold, well-oxygenated ground water is probably a factor that mitigates the potential effects of organic waste. Brook trout (*Salvelinus fontinalis*) of several age classes were collected during fish community sampling at this site in 1995 (Butch et al. 1996), supporting the hypothesis of mitigation of pollution impacts by cold, well-oxygenated groundwater inputs.

Sites 3 and 14 are "natural" according to ISD, but slightly impaired according to the Biological Assessment Profile. The classification of nonimpaired as "nonpoint nutrient" represents enrichment that has not gotten to the point of affecting a qualitative change from a nonimpaired site (RW Bode, NYSDEC, personal communication). However, a "natural" site should not be "slightly impacted." This discrepancy is likely due to the high relative abundances of *Micropsectra* at both these sites. *Micropsectra* is composed of species with widely different tolerances (R.W. Bode, NYSDEC, personal communication). However, because it is difficult to identify, it is typically identified to genus and given an "average" tolerance rating. The location of these sites in the CCA diagram near the low perturbation, low nutrient portions of the ordination plot, suggests that the Biological Assessment Profile is not representing conditions for this site as well as the ISD "natural" classification. Because NYSDEC has encountered this situation numerous times, and recognized the value of including this information in its ISD models, they have recently begun identifying *Micropsectra* to species for both their biomonitoring and for Impact Source Determination (R.W. Bode, NYSDEC, personal communication). Finally, the location of Site 6 in the ordination plot (Fig. 3) suggests misclassification by ISD. This site was classified by ISD as "nonpoint nutrient"-impacted, but it is located in the low nutrient portion of Axis II, and in the high runoff portions of Axis III (Figs. 3 and 4). *Microtendipes pedellus* (Diptera: Chironomidae), a relatively abundant taxon at this site, currently figures prominently in the "nonpoint nutrient" ISD model. Our results suggest this taxon might be a better indicator of siltation than of nutrients. Adjustment of the model could be warranted if future collections support this interpretation.

ISD appears to be able to discriminate fairly well among "nonpoint nutrient," "siltation," "complex" impairment sources, and "natural" communities. Yoder and Rankin (1995), using metric scores to determine impacts, had good success using Biological Response Signatures to discriminate between "Complex Toxic" and other sources. However, Biological Response Signatures was not as successful discriminating among their "municipal-conventional," "combined sewer overflow/urban," and "agricultural nonpoint" sources. Our results support their suggestion that better separation might be achieved with the use of more of the community information. The benefits of high-level taxonomic resolution in biomonitoring is a topic of investigation and debate (e.g., Bournand et al. 1996, Resh and Unzicker 1975), and many groups currently use family-level identification for their biomonitoring (e.g., Chessman 1995) while others use high-level taxonomic resolution (e.g., Bode et al.1996, DeShon 1995, Yoder and Rankin 1995). Although family-level resolution might be appropriate for broad scale monitoring programs, as suggested by Hewlett (2000), our results suggest that source identification is enhanced by high-level taxonomic resolution; this may be especially important when the need is to distinguish among nonpoint sources that have caused subtle impairment. The use of species-level identifications for selected taxa in ISD models is a currently evolving process; particular species are included in further refinements of the ISD as evidence suggests they are good at discriminating among sources. Our findings suggest that multivariate ordination and (or) similar approaches may help in this process by identifying selected taxa that might be useful in continued refinement of ISD. Our ordination plots show some congeneric species that are not currently incorporated at the species level in the ISD model, to be potentially important distinguishing between impact sources, according to their locations in the ordination diagrams (Figs. 3 and 4). Congeneric species, particularly those within the genera *Hydropsyche, Cricotopus,* and *Polypedilum*, were positioned near opposite ends of the CCA axes, indicating their associations for very different environmental conditions. Some of these taxa might be useful to incorporate into ISD models. ISD already incorporates *Polypedilum aviceps* as an indicator of clean-water "natural" streams; our findings support this because *P. aviceps* was located in the low pollution end of the ordination Axis I (Fig. 3), whereas *P. illinoense* was located near the high pollution end. Location of other congeners on ordination diagrams suggest they might also be important in distinguishing type of impairment. For example, *Hydropsyche betteni* and *H. bronta* are positioned near opposite portions of the runoff gradient (Fig. 4), which may indicate different tolerances to siltation and organic nutrients associated with runoff. ISD incorporates Hydropsychidae at the family level; our results suggest genus or species taxonomy might be useful in distinguishing certain impacts from others. Because most specimens in NYSDEC samples are already identified to species level, there would be no addition of effort to incorporate species level into the ISD model if further investigation suggests this is warranted. This is similar to findings of Yoder and Rankin (1995), where data collected for biomonitoring was able to be successfully applied to source identification because of a high level of taxonomic resolution, even though this was not the original objective of the collections. Because ISD is designed to reduce the effects of rare taxa (taxa present in less than five percent of the total abundance are not considered in the classification of samples), we would not expect the use of species-level resolution for additional taxa to require a larger subsample than the 100-specimen subsample that is currently in use.

Natural features such as elevation, stream size, and channel shape did not appear to be as important in our study as did land use. Ecoregion, which is commonly considered a useful environmental framework for biomonitoring studies, also did not appear to explain the patterns we identified. We limited our selection of sites to approximately second to fourth order streams, and selected sites with naturally-occurring riffle zones having gravel-cobble-boulder substrate. This appears to have limited much of the important natural variation among the sites in our study. Although ecoregional differences were seen in the organic enrichment / pollution gradient, these differences could be largely attributed to land use patterns. Early settlement in the Hudson River Basin was focused in the Hudson and Mohawk river valleys, where conditions for agriculture were better than in the highlands, and where the rivers were important in the development of towns and cities. It appears from our work that the heterogeneity of models within each ISD class fulfills its purpose of allowing for the differences attributable to natural variation, for the area we studied.

One way in which ISD differs from the Biological Response Signatures approach is that ISD does not use multiple organism groups. Whereas Biological Response Signatures uses both fish and benthic macroinvertebrates, ISD employs only benthic macroinvertebrates. NYSDEC has recently begun incorporating some fish community information in its biomonitoring process (e.g., Bode et al. 2000) and development of a fish index of biological integrity for the State or selected watersheds in the state is an ongoing effort by NYSDEC (Douglas Carlson, NYSDEC, personal communication), and other workers (e.g., Daniels et al., in press; Miller et al. 1988; Keller 1995). Recent work by Passy (2000) suggests that the incorporation of periphyton community information into NYSDEC's biomonitoring will be a useful complement to the benthic macroinvertebrate information, particularly in terms of source identification.

Results of this study suggest that the benthic macroinvertebrate data collected for establishing the degree of water quality impairment can also be used to identify the impairment source with reasonable accuracy, as determined by the concordance of the multiple lines of evidence. Future improvements in ISD can be made with increased taxonomic resolution and by fine tuning some of the model classifications. Our work was done on a few sites in one of New York's many river basins. The number of sites included in our study dictated that we could reasonably examine, at most, a small number of environmental gradients. Expansion of this verification of ISD with other sites across the State would be a useful endeavor.

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Appendix I. Impact Source Determination models. Number of individuals in a 100-specimen subsample of benthic macroinvertebrates, based on Bode et al. (in press).

	Natural												
Taxon	A	B	C	D	E	F	G	H	I	J	K	L	M
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-	-
Oligochaeta	-	-	5	-	5	-	5	5	-	-	-	5	5
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeriidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Asellidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammaridae	-	-	-	-	-	-	-	-	-	-	-	-	-
Isonychia	5	5	-	5	20	-	-	-	-	-	-	-	-
Baetidae	20	10	10	10	10	5	10	10	10	10	5	15	40
Heptageniidae	5	10	5	20	10	5	5	5	5	10	10	5	5
Leptophlebiidae	5	5	-	-	-	-	-	-	5	-	-	25	5
Ephemerellidae	5	5	5	10	-	10	10	30	-	5	-	10	5
Caenis/Tricorythodes	-	-	-	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	5	5	-	5	5	15	5	5	5	5
Psephenus	5	-	-	-	-	-	-	-	-	-	-	-	-
Optioservus	5	-	20	5	5	-	5	5	5	5	-	-	-
Promoresia	5	-	-	-	-	-	25	-	-	-	-	-	-
Stenelmis	10	5	10	10	5	-	-	-	10	-	-	-	5
Philopotamidae	5	20	5	5	5	5	5	-	5	5	5	5	5
Hydropsychidae, Helicopsychidae, Brachycentridae	10	5	15	15	10	10	5	5	10	15	5	5	10
Rhyacophilidae	5	5	-	-	-	20	-	5	5	5	5	5	-
Simuliidae	-	-	-	5	5	-	-	-	-	5	-	-	-
Simulum vittatum	-	-	-	-	-	-	-	-	-	-	-	-	-
Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	5	-	-	-	-
Chironomidae	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	5	-	-	-	-	-	-	5	-	-	-	-
Diamesinae	-	-	-	-	-	-	5	-	-	-	-	-	-
Cardiocladius	-	5	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/Orthocladius	5	5	-	-	10	-	-	5	-	-	5	5	5
Eukiefferiella/Tvetenia	5	5	10	-	-	5	5	5	-	5	-	5	5
Parametriocnemus	-	-	-	-	-	-	-		5	-	-	-	-
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	20	-	-	10	20	20	5	-
Polypedilum (all others)	5	5	5	5	5	-	5	5	-	-	-	-	-
Tanytarsini	-	5	10	5	5	20	10	10	10	10	40	5	5

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Appendix I. (continued).

	Nompoint Nutrients										Toxic					
Taxon	A	B	C	D	E	F	G	H	I	J	A	B	C	D	E	F
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	-			5	
Oligochaeta	-	-	-	5	-	-	-	-	-	15	-	10	20	5	5	15
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-
Sphaeriidae	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-
Asellidae	-	-	-	-	-	-	-	-	-	-	10	10		20	10	5
Gammaridae	-	-	-	5	-	-	-	-	-	-	5	-	-	-	5	5
Isonychia	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-
Baetidae	5	15	20	5	20	10	10	5	10	5	15	10	20	-	-	5
Heptageniidae	-	-	-	-	5	5	5	5	-	5	-	-	-	-	-	-
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Caenis/ Tricorythodes	-	-	-	-	5	-	-	5	-	5	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	5	-	-	5	-	5	5	-	-	-	-	-	-	-	-	-
Optioservus	10	-	-	5	-	15	5	-	5	-	-	-	-	-	-	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	15	15	-	10	15	5	25	5	10	5	10	15	-	40	35	5
Philopotamidae	15	5	10	5	-	25	5	-	-	-	10	-	-	-	-	-
Hydropsychidae, Helicopsychidae, Brachycentridae	15	15	15	25	10	35	20	45	20	10	20	10	15	10	35	10
Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	5	-	15	5	5	-	-	-	40	-	-	-	-	-	-	-
Simulum vittatum	-	-	-	-	-	-	-	-	5	-	-	20				5
Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Chironomidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	-	-	-	-	-	5	-	-	5	5	10	-	-	-	25
Diamesinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/ Orthocladius	10	15	10	5	-	-	-	-	5	5	15	10	25	10	5	10
Eukiefferiella/Tvetenia	-	15	10	5	-	-	-	-	5	-	-	-	20	10	-	-
Parametriocnemus	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
Microtendipes	-	-	-	-	-	-	-	-	-	20	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	10	20	10	5	10	5	5	10	-	-	-	-	5
Tanytarsini	10	10	10	5	20	5	5	10	-	10	-	-	-	-	-	5

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Appendix I. (continued).

	Siltation					Impoundment									
Taxon	A	B	C	D	E	A	B	C	D	E	F	G	H	I	J
Platyhelminthes	-	-	-	-	-	-	10	-	10	-	5	-	50	10	-
Oligochaeta	5	-	20	10	5	5	-	40	5	10	5	10	5	5	-
Hirudinea	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	10	-	5	5	-	-	-	-
Sphaeriidae	-	-	-	5	-	-	-	-	-	-	-	-	5	25	-
Asellidae	-	-	-	-	-	-	5	5	-	10	5	5	5	-	-
Gammaridae	-	-	-	10	-	-	-	10	-	10	50	-	5	10	-
Isonychia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Baetidae	-	10	20	5	-	-	5	-	5	-	-	5	-	-	5
Heptageniidae	5	10	-	20	5	5	5	-	5	5	5	5	-	5	5
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caenis/Tricorythodes	5	20	10	5	15	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
Optioservus	5	10	-	-	-	-	-	-	-	-	-	-	-	5	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	5	10	10	5	20	5	5	10	10	-	5	35	-	5	10
Philopotamidae	-	-	-	-	-	5	-	-	5	-	-	-	-	-	30
Hydropsychidae	25	10	-	20	30	50	15	10	10	10	10	20	5	15	20
Helicopsychidae, Brachycentridae, Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-
Simuliidae	5	10	-	-	5	5	-	5	-	35	10	5	-	-	15
Simulum vittatum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Empididae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Diamesinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/ Orthocladius	25	-	10	5	5	5	25	5	-	10	-	5	10	-	-
Eukiefferiella/Tvetenia	-	-	10	-	5	5	15	-	-	-	-	-	-	-	-
Parametriocnemus	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-
Chironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	5	5	5	-	-	20	-	-	5	5	5	5
Tanytarsini	10	10	10	10	5	5	10	5	30	-	-	5	10	10	5

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Appendix I. (continued).

	Organic										Complex						
Taxon	A	B	C	D	E	F	G	H	I	J	A	B	C	D	E	F	G
Platyhelminthes	-	-	-	-	-	-	-	-	-	-	-	40	-	-	-	-	-
Oligochaeta	5	35	15	10	10	35	40	10	20	15	20	20	70	10	-	20	-
Hirudinea	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	5	-
Gastropoda	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sphaeriidae	-	-	-	10	-	-	-	-	-	-	-	5	-	-	-	-	-
Asellidae	5	10	-	10	10	10	10	50	-	5	10	5	10	10	15	5	-
Gammaridae	-	-	-	-	-	10	-	10	-	-	40	-	-	-	15	-	5
Isonychia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Baetidae	-	10	10	5	-	-	-	-	5	-	5	-	-	-	5	-	10
Heptageniidae	10	10	10	-	-	-	-	-	-	-	5	-	-	-	-	-	-
Leptophlebiidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ephemerellidae	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Caenis/Tricorythodes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psephenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Optioservus	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-
Promoresia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Stenelmis	15	-	10	10	-	-	-	-	-	-	5	-	-	10	5	-	5
Philopotamidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hydropsychidae	45	-	10	10	10	-	-	10	5	-	10	-	-	50	20	-	40
Helicopsychidae, Brachycentridae, Rhyacophilidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simuliidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Simulum vittatum	-	-	-	25	10	35	-	-	5	5	-	-	-	-	-	-	20
Empididae	-	-	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-
Tipulidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tanypodinae	-	5	-	-	-	-	-	-	5	5	-	10	-	-	5	15	-
Diamesinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cardiocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cricotopus/Orthocladius	-	10	15	-	-	10	10	-	5	5	5	10	20	-	5	10	5
Eukiefferiella/Tvetenia	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parametriocnemus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomus	-	-	-	-	-	-	10	-	-	60	-	-	-	-	-	-	-
Polypedilum aviceps	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polypedilum (all others)	10	10	10	10	60	-	30	10	5	5	-	-	-	10	20	40	10
Tanytarsini	10	10	10	10	-	-	-	10	40	-	-	-	-	10	10	-	5

Appendix II. Abundance and frequency of occurrence of benthic invertebrate taxa in a collection from 26 stream sites in the Hudson River basin, NY, August, 1993. Taxa used in Canonical Correspondence Analysis are shown in bold.

CLASS ORDER FAMILY Taxon	Freq. (% of sites)	% of total collect.
ENOPLA		
HOPLONEMERTINI		
TETRASTEMMATIDAE		
Prostoma graecense(= rubrum)	11.5	0.2
TURBELLARIA		
Turbellaria (undet.)	3.8	0.1
OLIGOCHAETA		
LUMBRICINA		
Lumbricina (undet.)	34.6	1.2
LUMBRICULIDA		
LUMBRICULIDAE		
Stylodrilus heringianus	3.8	<0.1
Lumbriculidae (undet.)	3.8	0.15
TUBIFICIDA		
ENCHYTRAEIDAE		
Enchytraeidae (undet.)	7.7	3.0
NAIDIDAE		
***Nais* spp.**	19.2	0.6
Nais behningi	7.7	0.3
Nais bretscheri	7.7	0.1
Nais sp.	7.7	0.1
Nais variabilis	7.7	0.1
Pristina sp.	3.8	<0.1
Pristinella sp.	7.7	0.1
TUBIFICIDAE		
Limnodrilus hoffmeisteri	3.8	0.1
Tubificidae (undet.)	11.5	0.5
HIRUDINEA		
Hirudinea (undet.)	7.7	0.1
GASTROPODA		
BASOMMATOPHORA		
ANCYLIDAE		
***Ferrissia* sp.**	15.4	0.3
PHYSIDAE		
***Physella* sp.**	11.5	0.3
PLANORBIDAE		
Planorbidae (undet.)	7.7	0.1
PELECYPODA		
VENEROIDEA		
SPHAERIIDAE		
Pisidium sp.	3.8	<0.1
Sphaerium sp.	3.8	0.1
CRUSTACEA		
AMPHIPODA		
GAMMARIDAE		
***Gammarus* sp.**	3.8	0.8
DECAPODA		
CAMBARIDAE		
Cambaridae (undet.)	3.8	<0.1
ISOPODA		
ASELLIDAE		
***Caecidotea* spp.**	14	0.2
Caecidotea communis	8	0.2
Caecdotea sp.	12	0.2
INSECTA		
EPHEMEROPTERA		
BAETIDAE		
***Acentrella* sp.**	19.2	0.3
Acerpenna pygmaea	3.8	0.1
Baetidae (undet.)	11.5	0.1
Baetis flavistriga	11.5	0.3
***Baetis* sp.**	26.9	0.8
Baetis tricaudatus	11.5	0.3
Centroptilum sp.	3.8	0.1
CAENIDAE		
***Caenis* spp.**	31.0	1.3
Caenis anceps	11.5	0.3
Caenis latipennis	3.8	0.1
Caenis sp.	15.4	0.8
EPHEMERELLIDAE		
Drunella cornutella	3.8	1.0
***Serratella* spp.**	31.0	1.1
Serratella deficiens	11.5	0.5
Serratella serrata	11.5	0.3
Serratella sp.	11.5	0.2
HEPTAGENIIDAE		
***Epeorus* (Iron) sp.**	19.2	0.3
Heptageniidae (undet.)	3.8	<0.1
***Leucrocuta* sp.**	19.2	0.4
Nixe (Nixe) sp.	3.8	<0.1
***Stenonema* spp.**	46.2	2.2
Stenonema femoratum	3.8	<0.1
Stenonema integrum	3.8	<0.1
Stenonema sp.	42.3	2.2
LEPTOPHLEBIIDAE		
Leptophlebiidae (undet.)	15.4	0.2
Paraleptophlebia sp.	7.7	0.1
POLYMITARCYIDAE		
Ephoron leukon?	3.8	0.1
POTAMANTHIDAE		
***Anthopotamus* sp.**	11.5	0.6
TRICORYTHIDAE		
***Tricorythodes* sp.**	11.5	0.2
ISONYCHIIDAE		
Isonychia bicolor	50.0	3.8
ODONATA		
AESCHNIDAE		
Aeschnidae (undet.)	3.8	<0.1
Boyeria sp.	3.8	<0.1
CALOPTERYGIDAE		
Calopterygidae (undet.)	3.8	0.19
GOMPHIDAE		
Lanthus sp.	3.8	<0.1
PLECOPTERA		
LEUCTRIDAE		
Leuctra sp.	7.7	0.15
NEMOURIDAE		
Nemoura sp.	3.8	<0.1
PERLIDAE		
***Acroneuria* spp.**	15.4	0.38
Acroneuria abnormis	11.5	0.3
Acroneuria sp.	3.8	<0.1
Agnetina capitata	15.4	0.4
Paragnetina immarginata	3.8	<0.1
Paragnetina media	11.5	0.2
Perlidae (undet.)	7.7	0.3
PERLODIDAE		
Isoperla holochlora	3.8	<0.1

Appendix II, continued.

COLEOPTERA		
ELMIDAE		
Dubiraphia vittata	4	<0.1
Macronychus glabratus	4	0.2
***Optioservus* spp.**	65	4.4
Optioservus ovalis	27	1.0
Optioservus sp.	19	0.5
Optioservus trivittatus	35	2.9
Oulimnius latiusculus	11.5	0.2
Promoresia elegans	15.4	0.2
Promoresia tardella	7.7	0.4
Stenelmis spp.	73	5.9
Stenelmis concinna	8	0.2
Stenelmis crenata	27	4.0
Stenelmis mera	1 5	0.7
Stenelmis sp.	31	0.9
GYRINIDAE		
Dineutus sp.	8	<0.1
PSEPHENIDAE		
Ectopria nervosa	12	0.1
***Psephenus* spp.**	50	1.4
Psephenus herricki	35	0.9
Psephenus sp.	19	0.5
MEGALOPTERA		
CORYDALIDAE		
Nigronia serricornis	11.5	0.1
TRICHOPTERA		
BRACHYCENTRIDAE		
Brachycentrus appalachia	7.7	0.1
Brachycentrus solomoni	3.8	0.7
GLOSSOSOMATIDAE		
Glossosoma sp.	7.7	0.1
HYDROPSYCHIDAE		
Arctopsyche sp.	3.8	0.1
***Cheumatopsyche* sp.**	53.8	4.3
Hydropsyche betteni	23.1	1.4
Hydropsyche bronta	73.1	5.3
Hydropsyche dicantha	3.8	0.1
Hydropsyche morosa	26.9	2.8
Hydropsyche slossonae	11.5	0.6
***Hydropsyche* sp.**	23.1	1.5
Hydropsyche sparna	34.6	1.2
HYDROPTILIDAE		
***Hydroptila* sp.**	19.2	0.2
LIMNEPHILIDAE		
Neophylax sp.	3.8	<0.1
ODONTOCERIDAE		
***Psilotreta* sp.**	11.5	0.1
PHILOPOTAMIDAE		
***Chimarra* spp.**	42.0	0.7
Chimarra obscura ?	7.7	0.1
Chimarra sp.	15.4	0.6
***Dolophilodes* sp.**	19.2	1.2
Philopotamidae (undet.)	3.8	<0.1
POLYCENTROPODIDAE		
Neureclipsis sp.	3.8	<0.1
PSYCHOMYIIDAE		
Psychomyia flavida	3.8	<0.1
Psychomyiidae (undet.)	3.8	<0.1
RHYACOPHILIDAE		
Rhyacophila carpenteri ?	3.8	0.1
Rhyacophila fuscula	3.8	0.1

DIPTERA		
EMPIDIDAE		
***Hemerodromia* sp.**	30.8	0.4
ATHERICIDAE		
***Atherix* sp.**	34.6	1.1
SIMULIIDAE		
Simulium spp.	7.7	0.3
TIPULIDAE		
***Antocha* sp.**	11.5	0.2
***Dicranota* sp.**	7.7	0.5
***Hexatoma* sp.**	23.1	0.4
CHIRONOMIDAE		
Brillia sp.	3.8	<0.1
Cardiocladius obscurus	15.4	0.2
Cladotanytarsus sp.	3.8	<0.1
Corynoneura sp.	3.8	<0.1
Cricotopus bicinctus	46.2	1.5
***Cricotopus reversus* gr.**	11.5	0.3
***Cricotopus tremulus* gr.**	34.6	1.2
***Cricotopus trifascia* gr.**	34.6	2.3
Cricotopus vierriensis	26.9	2.0
***Diamesa* spp.**	11.5	0.4
Dicrotendipes neomodestus	3.8	<0.1
***Eukiefferiella brehmi* gr.**	3.8	0.4
Eukiefferiella claripennis gr.	3.8	<0.1
***Eukiefferiella devonica* gr.**	11.5	0.6
Eukiefferiella pseudomontana gr.	3.8	<0.1
***Micropsectra* spp.**	42.3	4.3
***Microtendipes pedellus* gr.**	30.8	2.3
***Microtendipes rydalensis* gr.**	11.5	0.2
Nanocladius (Plecopteracoluthus) sp.	3.8	<0.1
Nanocladius spiniplenus	3.8	<0.1
Natarsia baltimoreus	3.8	0.19
Natarsia sp. *A*	3.8	<0.1
Nilotanypus fimbriatus	7.7	0.1
Nilothauma sp.	7.7	0.1
Orthocladius* nr. *dentifer	26.9	1.3
***Pagastia* sp. A**	11.5	0.3
Paralimnophyes sp.	3.8	<0.1
Parametriocnemus lundbecki	34.6	1.7
Paratrichocladius sp.	3.8	0.1
Phaenopsectra dyari ?	3.8	<0.1
Polypedilum aviceps	57.7	3.8
Polypedilum fallax gr.	3.8	<0.1
Polypedilum flavum	57.7	2.9
Polypedilum illinoense	15.4	2.6
Polypedilum laetum	7.7	0.1
Polypedilum scalaenum gr.	7.7	0.19
Potthastia gaedii	15.4	0.2
Potthastia longimana	3.8	<0.1
Pseudochironomus sp.	3.8	<0.1
Rheocricotopus robacki	19.2	0.3
Rheotanytarsus distinctissimus gr.	7.7	0.1
Rheotanytarsus exiguus gr.	46.2	1.7
Stictochironomus sp.	7.7	0.1
Sublettea coffmani	38.9	0.8
***Tanytarsus glabrescens* gr.**	34.6	1.6
Tanytarsus guerlus gr.	3.8	<0.1
***Thienemanniella xena*?**	11.5	0.2
***Thienemannimyia* gr. sp.**	88.5	4.1
Tribelos jucundum	3.8	0.1
***Tvetenia bavarica* gr.**	23.1	0.6
Tvetenia vitracies	30.8	1.2
Xenochironomus xenolabis	3.8	<0.1
Zavrelia gr. spp.	3.8	<0.1