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DRAFT

Priority Rankings based on Estimated Restorability for Stream Segments in the DuPage-Salt Creek Watersheds

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Prepared for:

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Executive Summary

The DuPage River Salt Creek Work Group (DRSCWG) requested the development a framework for an active biological stressor prioritization system to support a quantitative decision-making process for developing restoration options for impaired reaches of streams and rivers in the DuPage and Salt Creek watersheds. The basis for this system is the recent monitoring and assessment results and GIS-based environmental infrastructure information that was developed for these watersheds in 2006-7. The goal was to develop a systematic process that provides reach level information on the most limiting stressors to biological attainment and a rating of the restorability of impaired reaches based on the information and processes contained in the five major factors that determine the integrity of aquatic ecosystems (Karr et al. 1986) which, in turn, are linked to the sources of these stressors. A major objective is to build this systematic framework using ambient data from specific stressor categories that includes habitat, hydrologic, water chemistry (water column and sediment), energy source (nutrients and nutrient processing), and biotic factors (alien and displaced species) and how these factors interact to influence the resulting biological condition and eventually the quality of ecosystem goods and services. A key requirement for making sound decisions regarding existing and needed management actions is correctly and comprehensively identifying the sources of stress and impairments. This is the important first step that is followed by further analyses of the observed biological relevant stressors that is needed to determine the feasibility of better managing and restoring the sources. As such we refer to this framework as the Integrated Priority System (IPS) that is comprised of the current most limiting stressors, the management actions that are needed to address the impairments, and the likelihood that those

management actions will succeed in either restoring impaired waters or at least result in incremental improvements towards that objective.

The framework that was developed herein develop includes a ranking of stream reaches based on a battery of analyses that relates current biological condition to the various stressor gradients that we either measured directly or that were inferred from the biological responses (stress:response). Widespread impairment of fish and macroinvertebrate assemblages using the current Illinois EPA framework for assessing impairments revealed widespread impairment in the DuPage-Salt Creek watersheds. A problem with relying only on this data to develop stress:response relationships is the potential skewing or under-estimation of those relationships. To provide a firmer basis for visualizing these conditions and to more accurately quantify these gradients we expanded the analyses to include “least impacted” reference and other sites from nearby Northeast Illinois watersheds. In effect this “lengthened” the biological quality gradient and provided a more complete analysis of stress:response relationships. The end result is a data set containing over 100 locations with matched chemical, physical and biological data that allowed for analysis and identification of the most proximate suite of stressors. As a long term approach to better understanding these relationships we also developed a Biological Condition Gradient (BCG; Davies and Jackson 2006) for Northeast Illinois Streams which included “synthetic” or computer modeled biological assemblages based on historical knowledge and information as well as predictions of changes in species/taxa abundances along similar gradients outside of the DuPage-Salt Creek watersheds. While the BCG is anchored in “natural” conditions that may only be attainable in a few places, its strength herein is the explicit visualization about how biological assemblages are expected to change along each stressor gradient. This will be used to identify realistically attainable assemblage conditions associated with feasible restoration endpoints along the stressor gradients.

The resulting rankings of restoration potential were necessarily be directed by the data and are compiled in a detailed spreadsheet (Appendix B). The algorithm used to prioritize the segments is based on percentile ranks of the number of identified stressors, magnitudes of biological departures, and the amount of open space adjacent to the reach. The basic assumption of the this scheme is that segments with relatively few stressors, modest biological impairments, and room for habitat restoration, are likely to respond faster to restoration actions than segments where the converse is true.

Introduction

A primary goal of the Clean Water Act is to restore beneficial uses to the Nation's surface waters. Understanding where presently impaired waters exist along a two dimensional continuum of biological integrity and anthropogenic stress, combined with information that describes the kinds and magnitudes of stressors acting on a given stream segment is an essential starting point for determining actions necessary for restoring beneficial uses. The 2008 DuPage River and Salt Creek Bioassessment Report (or Bioassessment Report for short) provided information required by the first part of the restoration process, especially with respect to the biotic integrity continuum and identifying causes and sources of impairment. However, a more detailed analysis of stressors is necessary to better understand where individual stream segments fall along the anthropogenic continuum. This document describes the analyses used to determine the number, types and magnitude of stressors acting on stream segments in the DuPage River-Salt Creek watersheds, and applies the resulting information to classify stream segments based on their respective degrees of impairment and suite of stressors. The resulting knowledge then forms the basis of a systematic and comprehensive mechanism for identifying projects that have a high probability of restoring beneficial uses to stream segments in the DuPage River and Salt Creek watersheds, and brings the process of bioassessment, stressor identification, and delineation of the stressor gradient full circle to application in resource management. Note that the term "restorability" is used throughout the document as shorthand to connote the temporal susceptibility of a given stream reach to management, and should not be construed to denote a hierarchy of intrinsic value between segments.

Methods

Data used in these analyses were collected during 2006-07 Biological and Water Quality Survey of the DuPage River and Salt Creek watersheds. The scope, study design and media sampled and parameters collected are detailed in the Bioassessment Report, but briefly, water quality and biological samples for the survey were collected from an array of sites systematically placed at successive fixed intervals of decreasing drainage area starting at the watershed terminus working down (in terms of drainage area) to stream locations draining approximately 2 square miles. These sites were supplemented with targeted samples (as detailed in the Bioassessment Report). The end result is a data set containing over 100 locations with matched chemical, physical and biological data that allows for a robust analysis in support of identifying the most proximate suite of stressors and positioning streams along the disturbance gradient. Additionally, fish, habitat and water chemistry data from a study on urbanization in the Fox and Des Plaines River Basins by Harris et al. (2005) were included to expand the range of land use away from high-density urban that predominates the DuPage-Salt Creek watersheds by including less urbanized sites north of the Chicago Metropolitan area. The Harris et al. (2005) data collection occurred during 2000 and 2001. See Appendix A for a list of sites included in the analyses.

The analytical process (Table 1) used to identify and gauge the magnitude of stressors acting on the fish and macroinvertebrate communities was essentially a two-step process that involved first grouping sites by biological attributes (Morris et al. 2006), then examining patterns in stressors that best explain group formation using a variety of statistical methods (*sensu* US EPA's CADDIS application; web site: http://cfpub.epa.gov/caddis/index.cfm). Cluster analysis and non-metric multidimensional scaling (NMDS) based on Bray-Curtis (Bray and Curtis, 1957) distances were the computer algorithms used to identify groups based solely on biological attributes. Cluster analysis assigns sites into categorical groups, whereas NMDS arranges sites on a continuum of one or more axes, with the obvious advantage that a continuous-scale ordination can be readily plotted and visually compared to various stressor variables. Categorical groupings have the advantage of providing an objective basis for testing statistical differences in stressor levels between groups, and for identifying stressors that best explain separation between groups.

Table 1. Summary of methods used to gauge restorability of stream segments in the DuPage River and Salt Creek watersheds.

Analytical Step	**Statistical Tool**	**Purpose and Brief Description of Method**
Group sites based on similarities in fish and macroinvertebrate attributes.	Cluster Analysis	Use an established algorithm to objectively identify groups of sites without having to rely on BPJ. (Sites are grouped by shared attributes and abundances that minimize within group differences and maximize between group differences).
Validate groups using a second algorithm.	Non-metric Multidimensional Scaling (NMDS)	Visualize how well sites group together in two, three or multidimensional space, and check for consistency between methods.
Determine which environmental variables explain group formation or group separation.	Correlation of environmental variables with axis scores from NMDS; Discriminant Analysis	Identify stressors.
Validate stressors identified in the previous step.	Classification and Regression Trees (CART)	Identify stressors using mIBI or fIBI scores instead of metric values or assemblage attributes. CART also groups sites, but does so based on environmental variables, rather than assemblage attributes. Similar site groups formed by similar environmental stressors between the CART and NMDS methods adds confidence and helps to build a general conceptual model linking stressors to biological performance.

Table 1. Summary of methods used to gauge restorability of stream segments in the DuPage River and Salt Creek watersheds.

Analytical Step	**Statistical Tool**	**Purpose and Brief Description of Method**
Validate conceptual model identified in the previous step.	Structural Equation Modeling (SEM)	Relationships between biological measures and environmental variables are often confounded by a relatively high degree of inter-correlation between environmental variables. SEM helps confirm that a general linear model applied to an environmental data set is consistent with respect to variances and covariances among the explanatory variables in the model.
Identify thresholds or critical values in environmental variables that demarcate significant changes (positive or negative) in biological quality.	Additive Quantile Regression, CART	Identify components of the physical environment or water quality where directed management will likely have a direct positive effect on moving the system toward meeting beneficial uses. Additive quantile regression identifies thresholds by determining where significant changes occur in a relationship between a response and explanatory variable.
Cross tabulate proximate environmental variables (i.e., those identified in the preceding steps) with individual sites, and aggregate to stream segments.	Spreadsheet/GIS manipulation	Determine the number of proximate stressors co-occurring at a given site and within a given segment as a first order approximation of the amount and degree of remedial action needed to bring the segment into attainment.
Tally how far biological scores deviate from attainment thresholds and aggregate to specific segments.	Spreadsheet/GIS manipulation	Approximate how far a given segment has to travel to meet the beneficial aquatic life use. Thresholds for mIBI (41.8) and fIBI (41) scores are based on IEPA (2010).

Another method used to help discern the stressor gradient was classification and regression tree (CART) analysis. CART is a direct method that categorizes either the macroinvertebrate Index of Biotic Integrity (mIBI) or the fish IBI into one or more groups by partitioning the variance in index scores by one or more stressor variables. By comparing the results from the CART and clustering methods, a high level of confidence can be placed on the role of a stressor in cases where the two methods form similar groups, and the same stressor separates or associates with the groups.

Following identification of the most proximate biological stressors, a conceptual model relating the stressors to biological integrity is built and tested using a method know as structural equation modeling (SEM). SEM is a confirmatory approach that tests whether the observed covariances and correlations between variables in a multivariate model fit predictions. This method also helps describe hierarchical and co-linear relationships between stressors.

Lastly, thresholds between biological index scores and the individual stressors identified from the preceding analyses were identified using quantile regression. Quantile regression helps describe the bivariate relationship between a response variable (i.e., either the mIBI or fIBI) and a single explanatory variable in cases where that relationship is clouded by other explanatory variables.

Results and Discussion

Figures 1 and 2 show the dendrograms based on cluster analysis of macroinvertebrate and fish biological attributes. The macroinvertebrates separate into two well-defined groups, with several candidate subgroups under each of the two branches. Similarly, the fish assemblage separates into two groups, but the subgroups are more ambiguous, and two sites are clearly outliers. Superimposing the macroinvertebrate groups from the cluster analysis on a plot of NMDS scores (Figure 3) reveals that the two methods separate the sites along a gradient of physical variables including drainage area and various habitat attributes. Clearly drainage area is not a stressor gradient; however, several environmental variables correlate with drainage area, notably the number of modified habitat attributes, ammonia-nitrogen, and road density (Table 2). In all cases, the direction of increasing environmental stress is toward smaller streams. The strength of association between drainage area and macroinvertebrate attributes potentially suggests an artifact of calibration (or lack of calibration) between the mIBI and drainage area. However, residuals from a regression of mIBI scores on drainage did not show any tendency toward stronger or weaker correlations with the environmental variables compared to the mIBI, which suggests that the mIBI was tracking the environmental gradient (i.e., if the mIBI was simply tracking drainage area because of lack of calibration, the residuals would have shown no, or very low correlation with the environmental stressors that were correlated with drainage area). Habitat attributes are stressors when they represent degrees of anthropogenic modification. The NMDS plot of fish scores (Figure 4) suggests that, compared to the macroinvertebrates, fish assemblages are uniformly degraded in the DuPage River-Salt Creek watershed and are consequently less well-explained by the measured environmental gradients.

CART analysis partitioned the mIBI scores by drainage area, dissolved solids, road density, habitat quality, and ammonia nitrogen (Figure 5). The subgroup defined by poor habitat quality lacked functional riffles. The branch representing comparatively small streams was split into two groups by dissolved solids, and further split by road density. Essentially, this can be read as small streams subject to the least amount of urbanization fare better than more developed small streams. The five sites with the best habitat quality and the least amount of organic

Table 2. Correlations between environmental variables and drainage area, mIBI scores and residual variation in mIBI scores following regression on drainage area; continues on next page.

Variable	Drainage Area	mIBI	Residual mIBI
Number of negatively influential habitat attributes characteristic of modified stream channels	-0.42	-0.39	-0.18
Nitrogen to phosphorus ratio (phosphorus loading from point sources increases in a downstream direction)	-0.33	-0.33	-0.18
Ammonia-nitrogen	-0.27	-0.35	-0.23
Road density	-0.24	-0.39	-0.31
Biochemical oxygen demand	-0.22	-0.43	-0.37
Residential development within 1000 m of the stream channel	-0.18	-0.28	-0.21
Total dissolved solids & Chloride	-0.15	-0.29	-0.25
Total residential development in the subcatchment upstream from the sampling point	-0.15	-0.12	-0.04
Industrial development within 500 m of the stream	-0.12	-0.12	-0.06
Residential development within 500 m of the stream	-0.11	-0.19	-0.15
Total Kjeldahl nitrogen	-0.10	-0.39	-0.41
Transportation infrastructure within 500 m of the stream channel	-0.09	-0.02	0.04
PH	-0.08	-0.32	-0.33
Transportation infrastructure within 1000 m of the stream channel	-0.06	-0.15	-0.15
2-yr peak flow adjusted for drainage area	-0.05	-0.12	-0.11
Unclassified land uses within 500 m of the stream channel	-0.04	-0.01	0.02
Industrial land use land uses within 1000 m of the stream channel	-0.03	0.05	0.08
Agricultural land uses within 1000 m of the stream channel	-0.01	0.18	0.22
Commercial land uses within 500 m of the stream channel	0.00	-0.13	-0.16
Total transportation infrastructure upstream from the sampling point	0.01	-0.14	-0.18
Commercial land uses within 1000 m of the stream channel	0.05	-0.02	-0.06
Total open land uses upstream from a sampling point	0.06	-0.02	-0.07
Unclassified land uses within 1000 m of the stream channel	0.06	0.03	0.00
Total amount of industrial land uses upstream from a sampling point	0.07	-0.01	-0.06
Open land uses within 500 m of the stream channel	0.07	-0.07	-0.14
Open land uses within 1000 m of the stream channel	0.09	-0.10	-0.18
Total commercial land use upstream from a sampling point	0.13	0.13	0.07
Substrate quality	0.15	0.21	0.15
Channel quality	0.16	0.40	0.38
Forest cover within 1000 m of the stream channel	0.19	0.37	0.32
Forest cover within 500 m of the stream channel	0.19	0.30	0.23
Riffle quality	0.20	0.32	0.25
Nitrate nitrogen	0.22	-0.14	-0.33
QHEI	0.32	0.36	0.21
Total suspended solids	0.34	0.17	-0.03
Total forest cover upstream from a sampling point	0.34	0.28	0.10
Riparian quality	0.36	0.48	0.34
Total unclassified land uses upstream from a sampling point	0.40	0.23	-0.01
Total phosphorus	0.42	0.25	0.00
Pool quality	0.45	0.36	0.12
Drainage area	1.00	0.58	0.00

enrichment, as evidenced by ammonia nitrogen, had an average mIBI score consistent with the minimum expectation for the beneficial aquatic life use.

Groups formed based on the cluster analysis of macroinvertebrate assemblage attributes were arrayed along a gradient of habitat quality (Figure 3). To better define the groupings, and the variables that explained separation of the groups, a discriminant analysis (DA) was performed. DA looks for linear combinations of independent (i.e., explanatory or stressor) variables that best predict group membership. Where groups defined by a cluster analysis are ill-defined by DA, those groups can be collapsed back to a higher group, thus helping to identify functional groupings. The results of DA performed in this manner suggest that there are effectively three groups, with two groups being separated by a linear combination of drainage area, riffle quality, and pH; pH as an explanatory variable is something of mystery, but may be serving as a proxy for chloride ions, organic enrichment, or nutrient enrichment. In pair wise comparisons of TKN and pH concentrations between groups, both TKN and pH were significantly higher in the second group (Group B in Figures 6 and 7) compared to the other two groups. As for nutrient enrichment, note that pH covaries with dissolved oxygen as carbon dioxide is taken up during photosynthesis. Results from automated data loggers deployed in the watershed demonstrated alkaline conditions when dissolved oxygen concentrations were driven toward super-saturation (Figure 8). Also note that pH tended to vary with longitude, such that streams in the eastern half of the watershed were more alkaline than those to the west, coincident with the general trend of urban land use. The third group, though initially poorly defined, was explained by a combination of drainage area and riparian quality after two-outliers were excluded from the analysis (Figure 6).

Rarifying the above analyses suggests that a general conceptual model explaining mIBI scores is a combination of drainage area, habitat quality as defined riffle and riparian scores, water quality as defined by either organic enrichment (TKN, BOD, NH3), dissolved ions (chloride, TDS), or pH, and land use (given by urban land, forest in the 1000 upstream buffer, or road density). Testing this model iteratively suggested that the model was conceptually sound (Figure 9), and that ambiguity between water quality variables was resolved by including organic enrichment (with TKN as a proxy) in the model in lieu of dissolved ions or pH. Similarly, total urban land cover, and the amount of forest cover in the 1000 m zone immediately upstream from a sampling location resolved ambiguity between land use variables. Note that organic enrichment is positively associated with percent urban land use and negatively associated with riparian quality. Concentration scales for TKN and chloride are based on log10 of the concentrations in µg/l.

The fIBI scores were split by CART analysis first by drainage area, and further subdivided by chloride ions and the amount of forest cover in the watershed upstream from a sampling point (Figure 10). Note that the mean fIBI values within the terminal nodes range from 12 to 25. To expand the gradient of biological condition and anthropogenic stress, fIBI scores, habitat and water quality, variables and land use from a USGS urban gradient study of streams in the Northeastern Illinois area were appended to the data from the DuPage River-Salt Creek study.

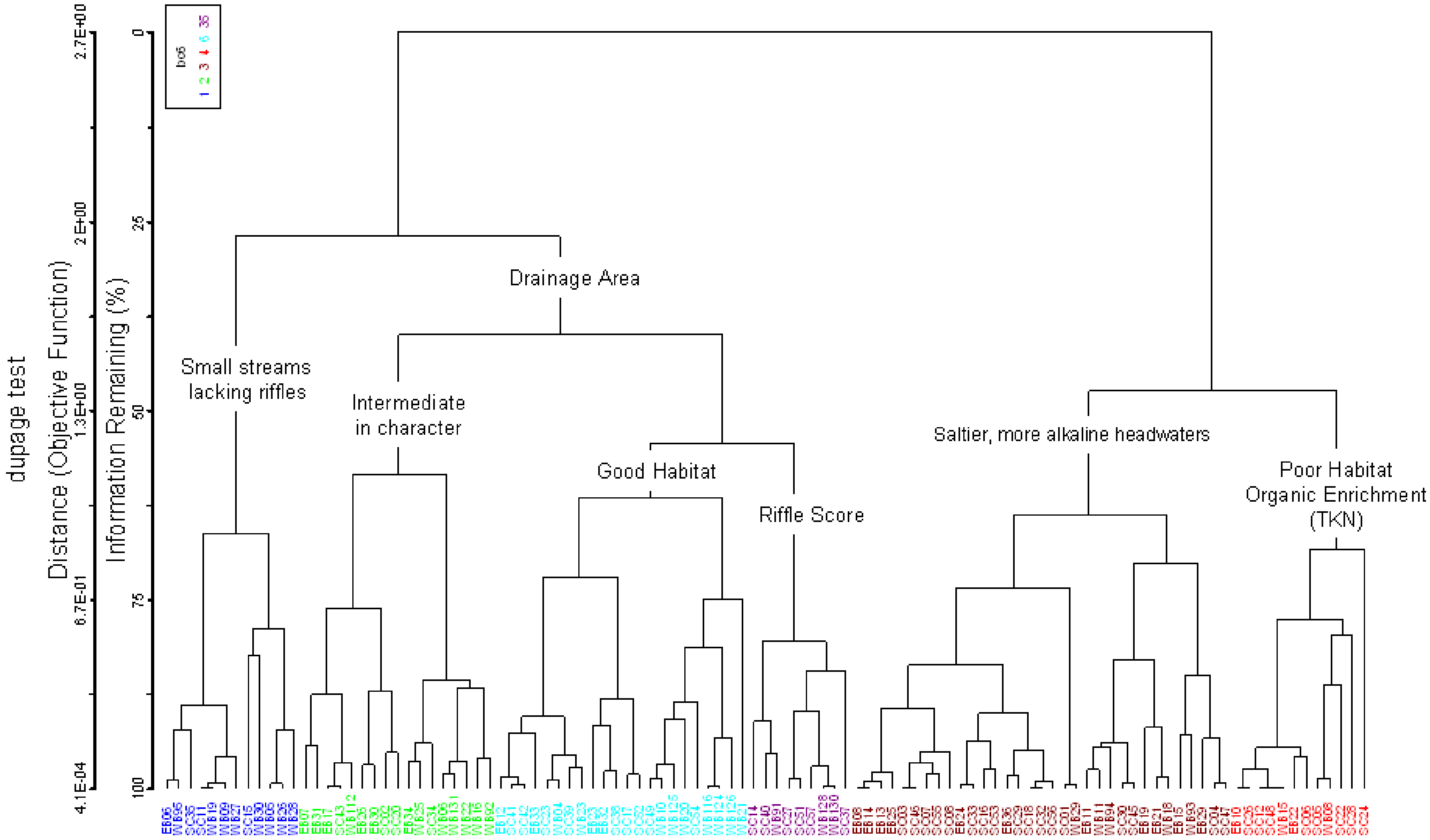


Figure 1. Cluster dendrogram based on Bray-Curtis similarity of macroinvertebrate assemblage attributes for sites in DuPage River-Salt Creek watersheds.

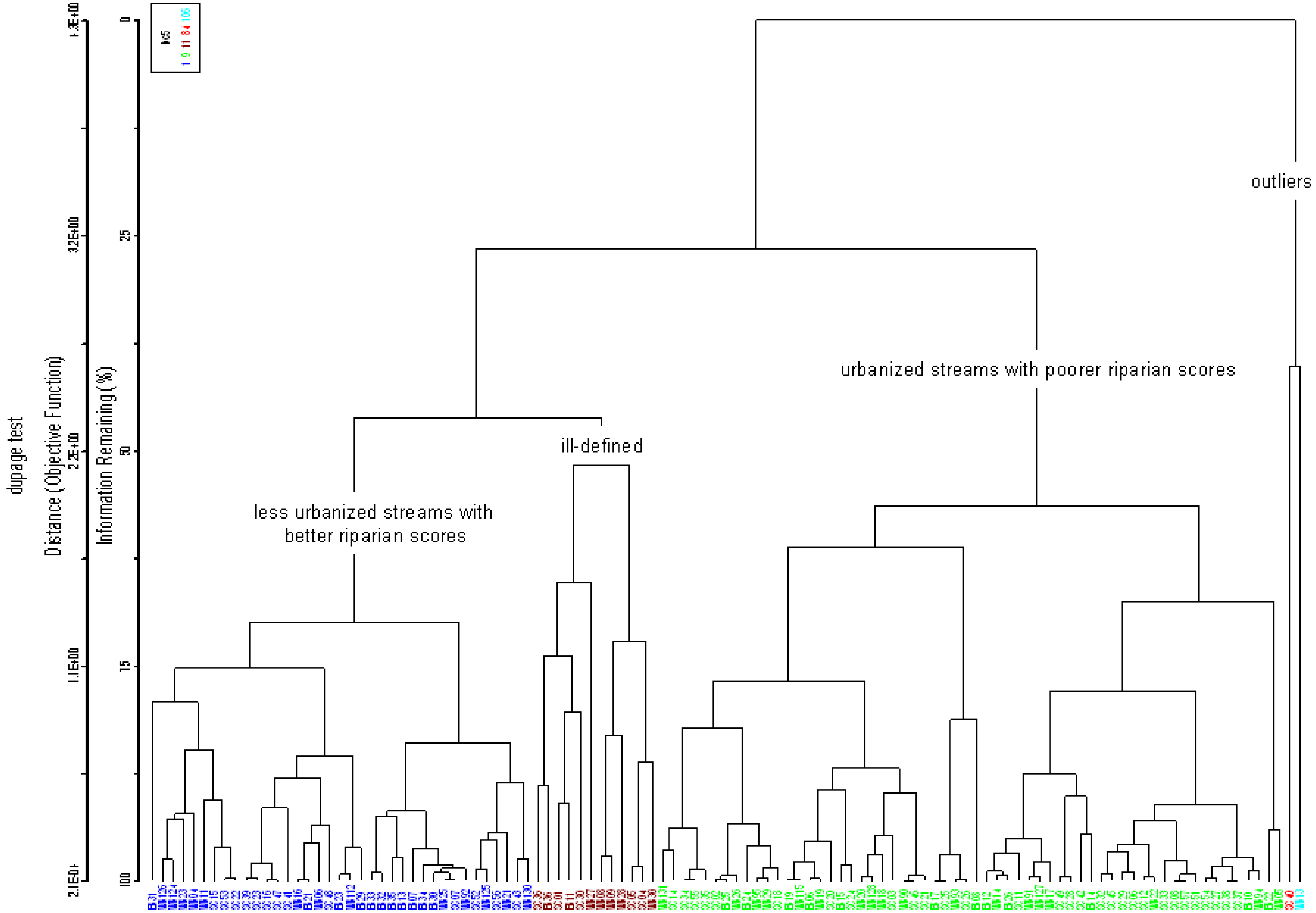


Figure 2. Cluster dendrogram based on Bray-Curtis similarity of fish assemblage attributes for sites in DuPage River-Salt Creek watersheds.

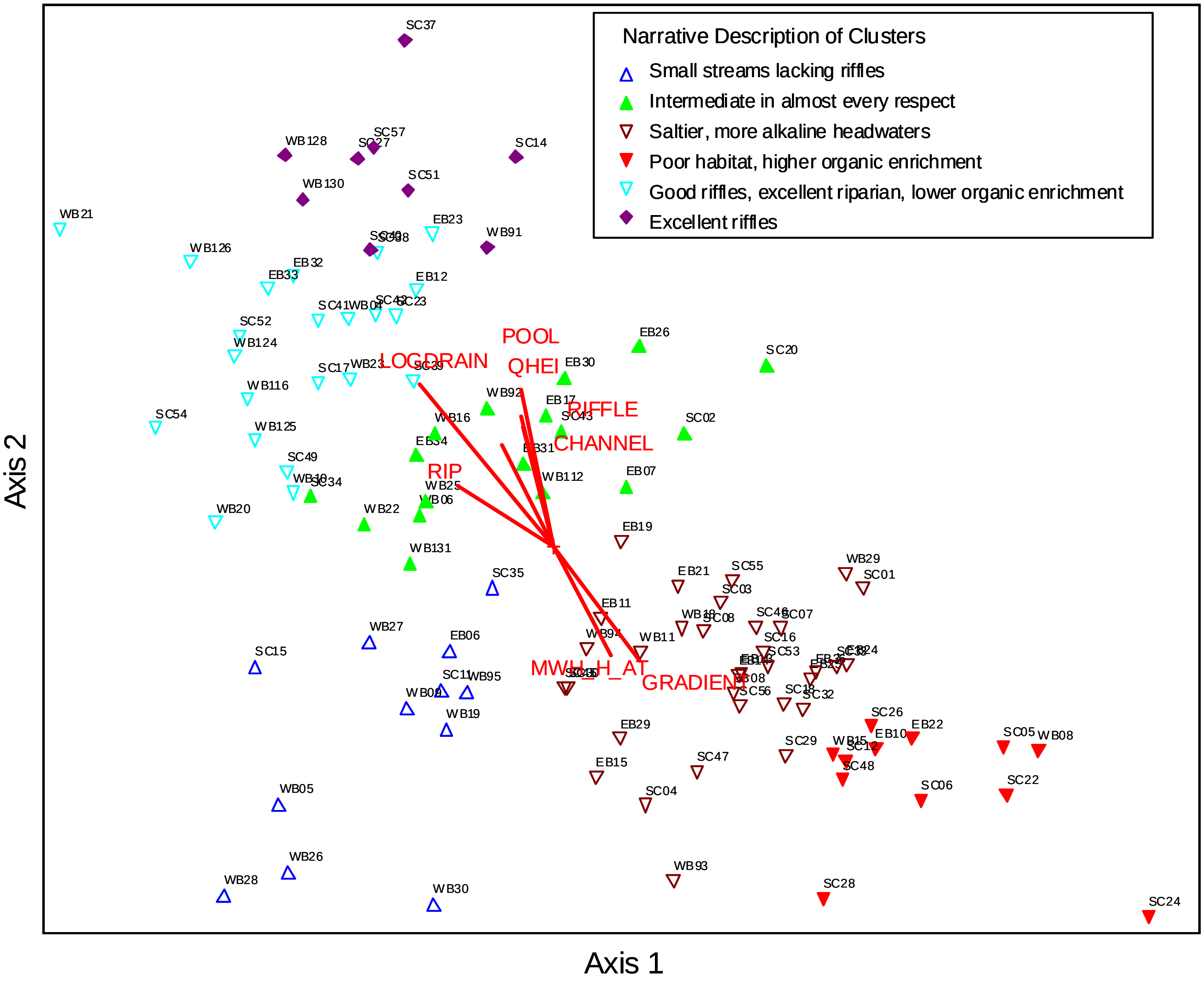


Figure 3. Site scores based on non-metric multidimensional scaling of macroinvertebrate assemblage attributes coded by cluster groups. Environmental variables showing a relatively high degree of correlation (correlation coefficient > 0.44) with site scores are superimposed on the graph as red lines. The narrative descriptions of cluster groups are relative, not absolute, not completely inclusive for brevity, and show the environmental variable(s) that best associates with the group. The final stress from the 2-dimensional solution = 6.9661.

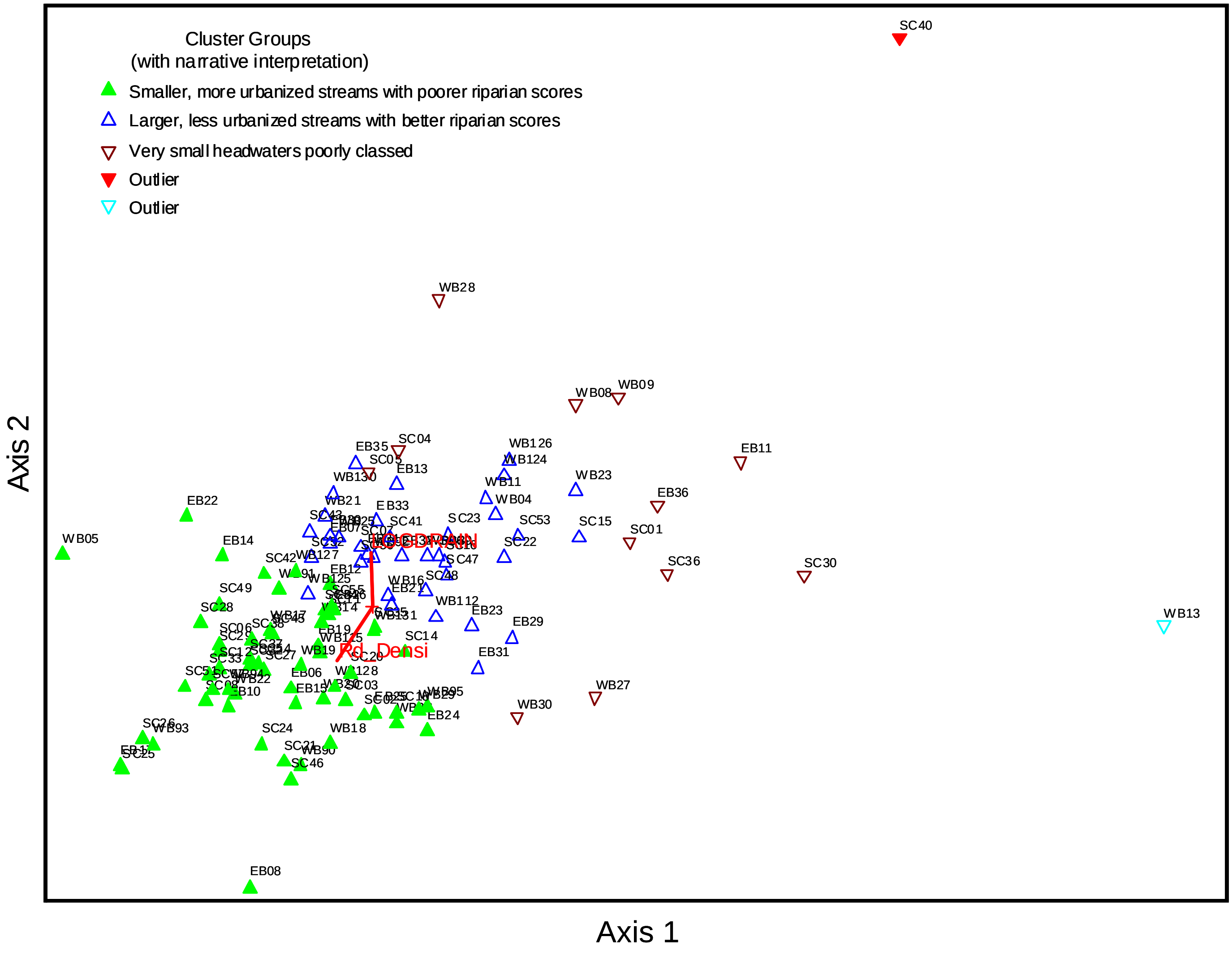


Figure 4. Site scores based on non-metric multidimensional scaling of fish assemblage attributes coded by cluster groups. Environmental variables showing a relatively high degree of correlation (correlation coefficient > 0.30) with site scores are superimposed on the graph as red lines. The narrative descriptions of cluster groups are relative, not absolute, not completely inclusive for brevity, and show the environmental variable(s) that best associates with the group. Final stress for the 2-dimensional solution = 10.0372.

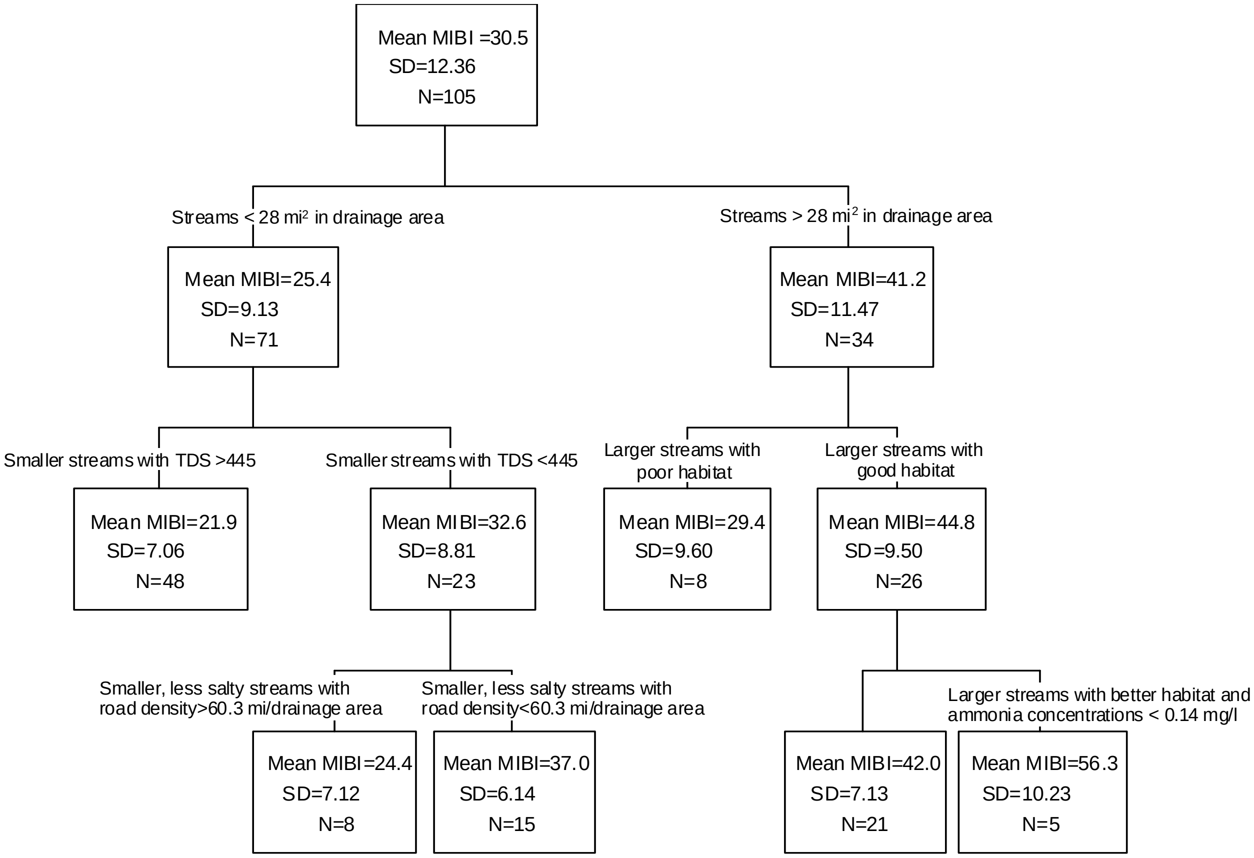


Figure 5. Classification and regression tree for mIBI scores as partitioned by environmental variables.

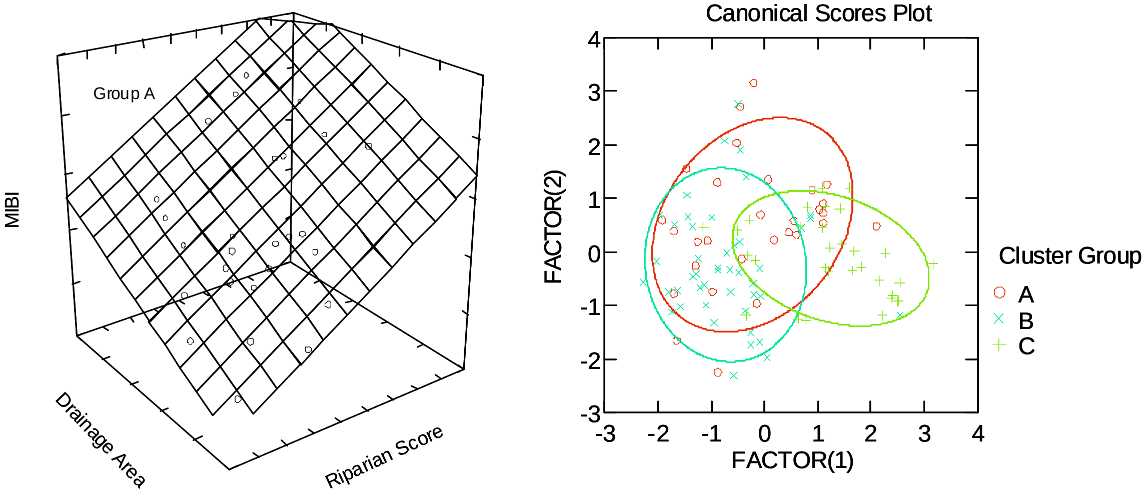


Figure 6. Visual representation of discriminant functions separating macroinvertebrate cluster groups. Group B and C in the plot on the right are effectively separated by a linear combination of drainage area, riffle scores and pH. Drainage area and riparian scores explain two-thirds of the variance in group A.

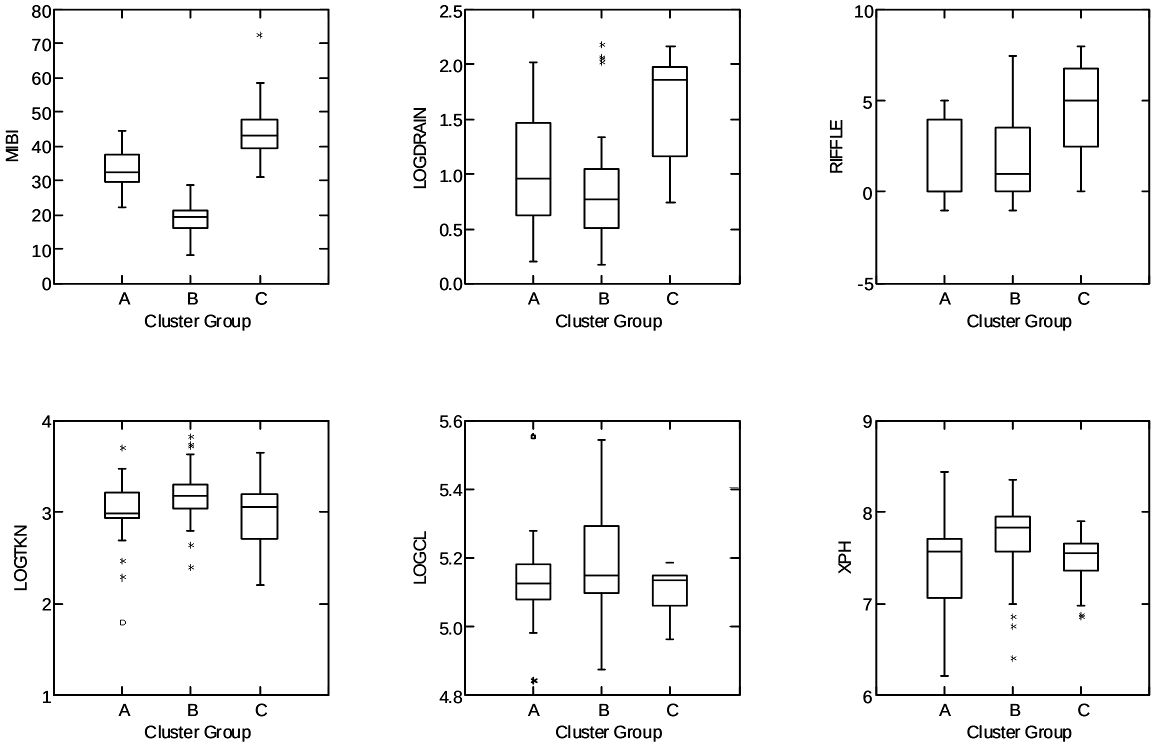


Figure 7. Distributions of mIBI scores and selected environmental variables within cluster groups.

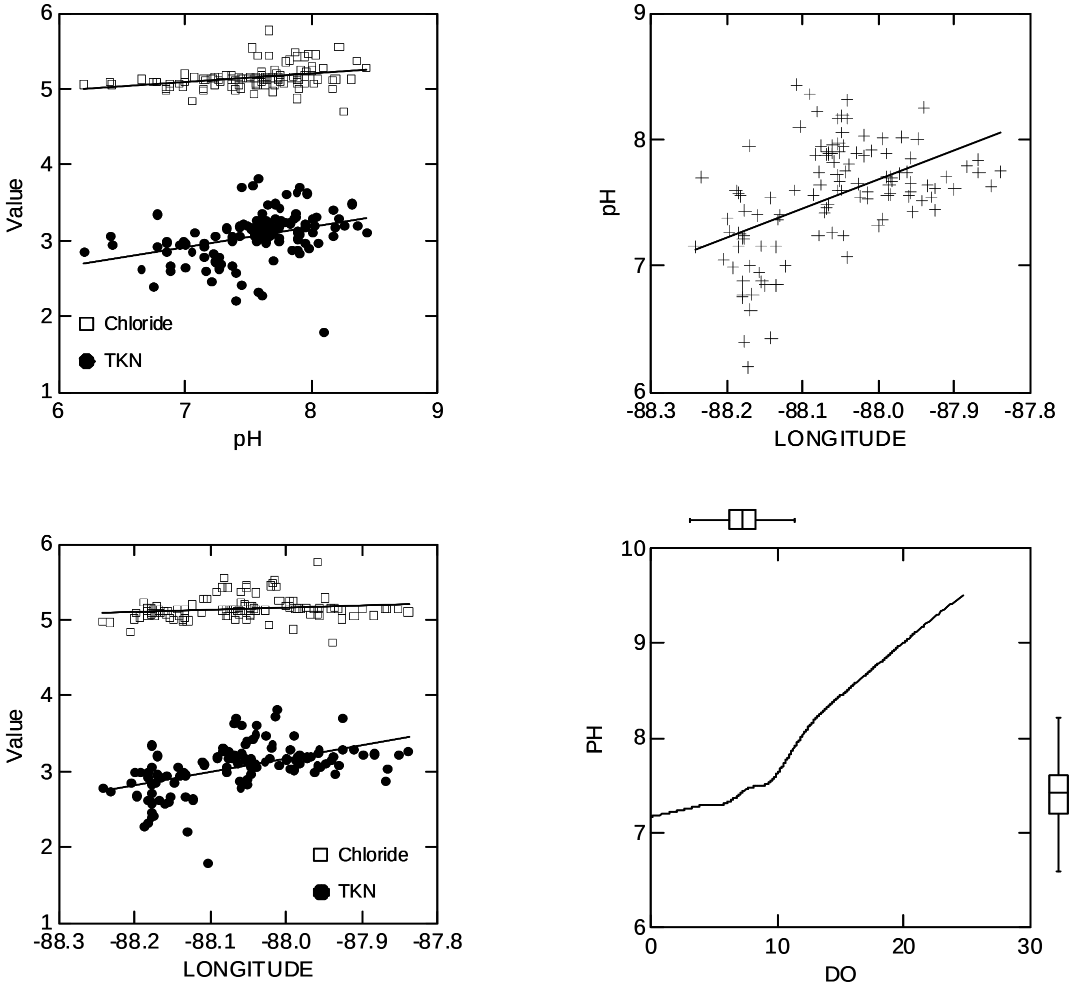


Figure 8. Clockwise from top left, chloride and TKN concentrations as a function of pH, pH as a function of longitude, chloride and TKN concentrations as a function of longitude, and pH as function of dissolved oxygen concentrations (DO). Data for the latter are from automated data loggers; box and whisker plots on the borders show the respective distributions.

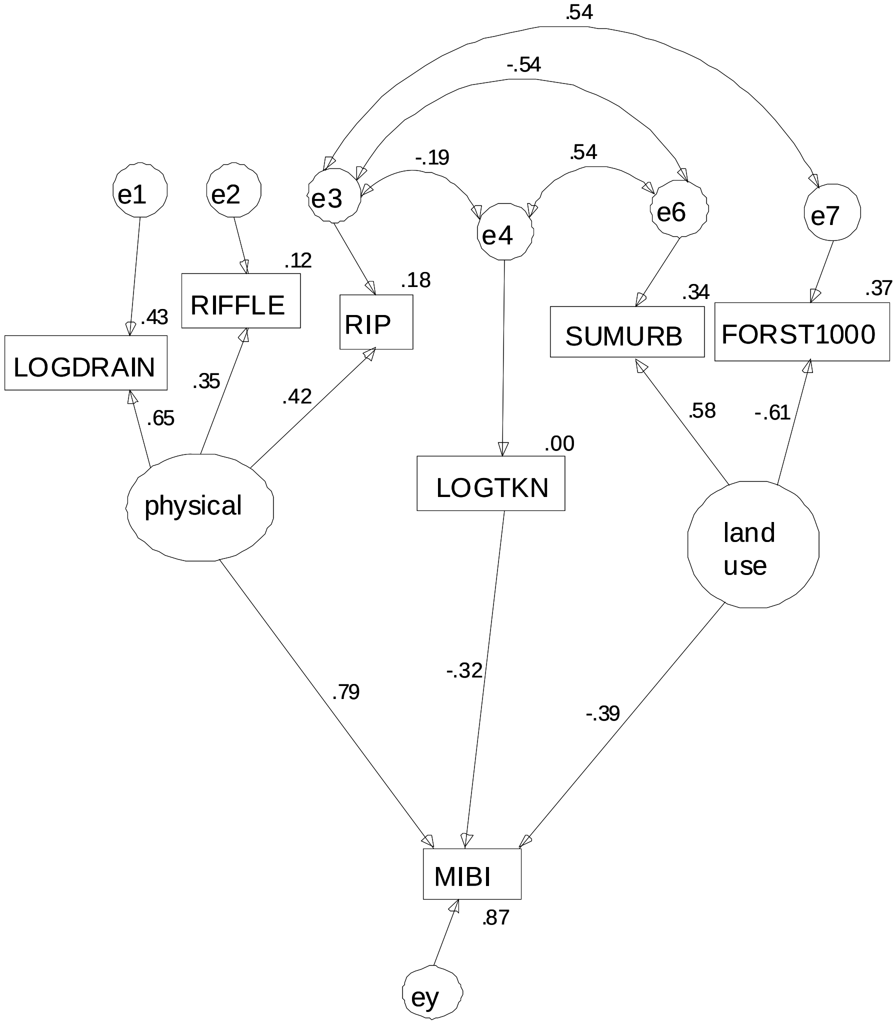


Figure 9. A structural equation model that relates physical variables, land use variables, and an indicator of organic enrichment to mIBI scores. The model explains 87 percent of the variance in mIBI scores.

A CART analysis ran against the combined data set illustrate the point of fIBI scores from the DuPage River-Salt Creek study being uniformly degraded (Figure 11). Percent urban land cover formed the first split, binning most of the DuPage-Salt sites into a single node that was further split by drainage area.

Conceptually, the CART analysis suggests that fIBI scores are explained by a combination of drainage area, land use and water quality. One could reasonably include habitat quality in the model, given overwhelming past experience. A structural equation model based on these parameters Figure 12 suggest that urban land use has the strongest direct and total effect on fIBI scores. The total effect of urban land use is worked indirectly through ammonia nitrogen, which is predicted by urban land use. Habitat quality comes into play in the form of substrate quality. Again, substrate quality directly impacts fIBI scores, and indirectly by apparently mediating ammonia nitrogen concentrations.

Relationships between biological communities and environmental gradients are complex, and generally not strictly linear. Notable exceptions include toxicants like ammonia-nitrogen or free chlorine. More typically, biological communities show threshold responses to environmental gradients; familiar examples include dissolved oxygen and temperature. Occasionally, relationships are non-monotonic. Dissolved oxygen, again, proves the point, as supersaturating concentrations of dissolved oxygen can cause gas bubble disease in fish and macroinvertebrates. Where thresholds can be identified between biological indicators and environmental gradients, those thresholds can be used to help assess the likely effectiveness of a restoration project, or better, direct the effort starting at the design phase.

Clear thresholds between mIBI or fIBI scores were observed for eight of the environmental variables identified as being the most likely proximate controlling variables (Table 1; Figures 13 and 14). These thresholds were used to rank stream segments in the DuPage River-Salt Creek study area by the number of the thresholds exceeded within a segment. The rankings can serve a rough first approximation of restorability, and to direct attention to which factors are most limiting within a segment. Clearly, the rankings need to be interpreted in light of all available

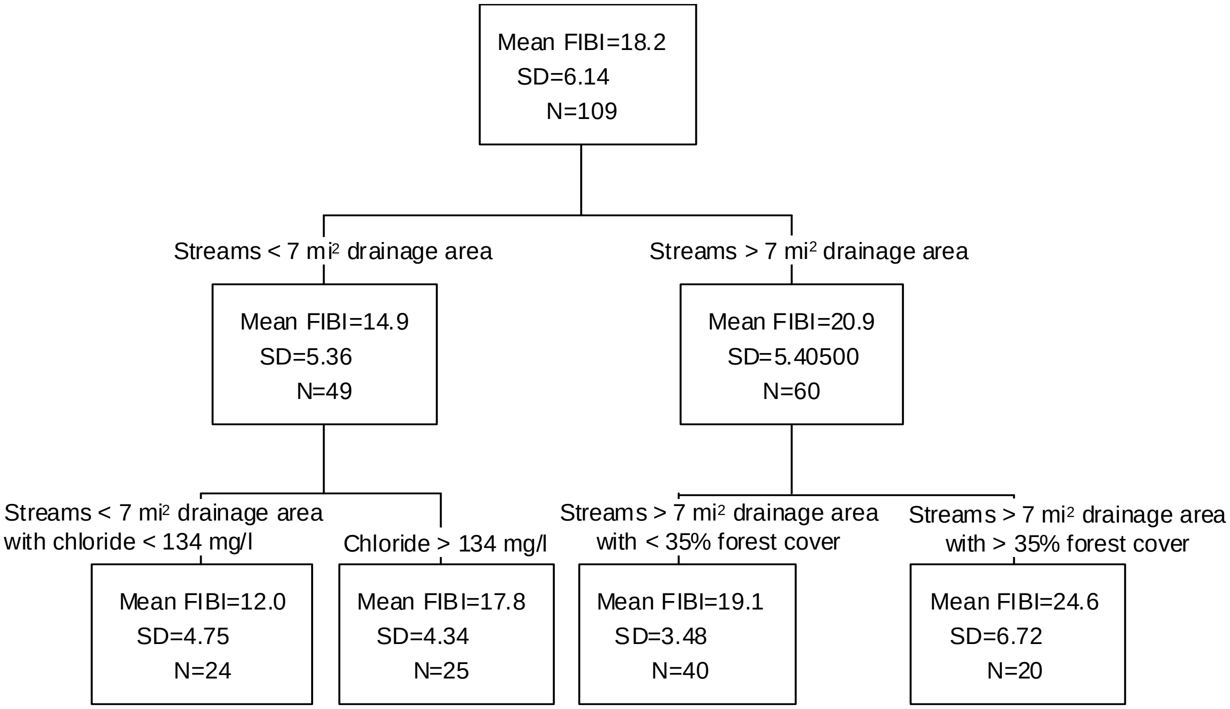


Figure 10. Classification and regression tree for fIBI scores as partitioned by environmental variables. Data are from the DuPage-Salt Creek study only.

evidence. For example, a segment rated as restorable based on environmental thresholds, but severely degraded may not necessarily be a candidate for restoration. Figure 15 compares segments by threshold rankings and the degree of biological impairment within the segment. Superimposing the two plots suggests that, for example, the lower reach of Salt Creek has significant restoration potential, as does much of the West Branch DuPage mainstem.

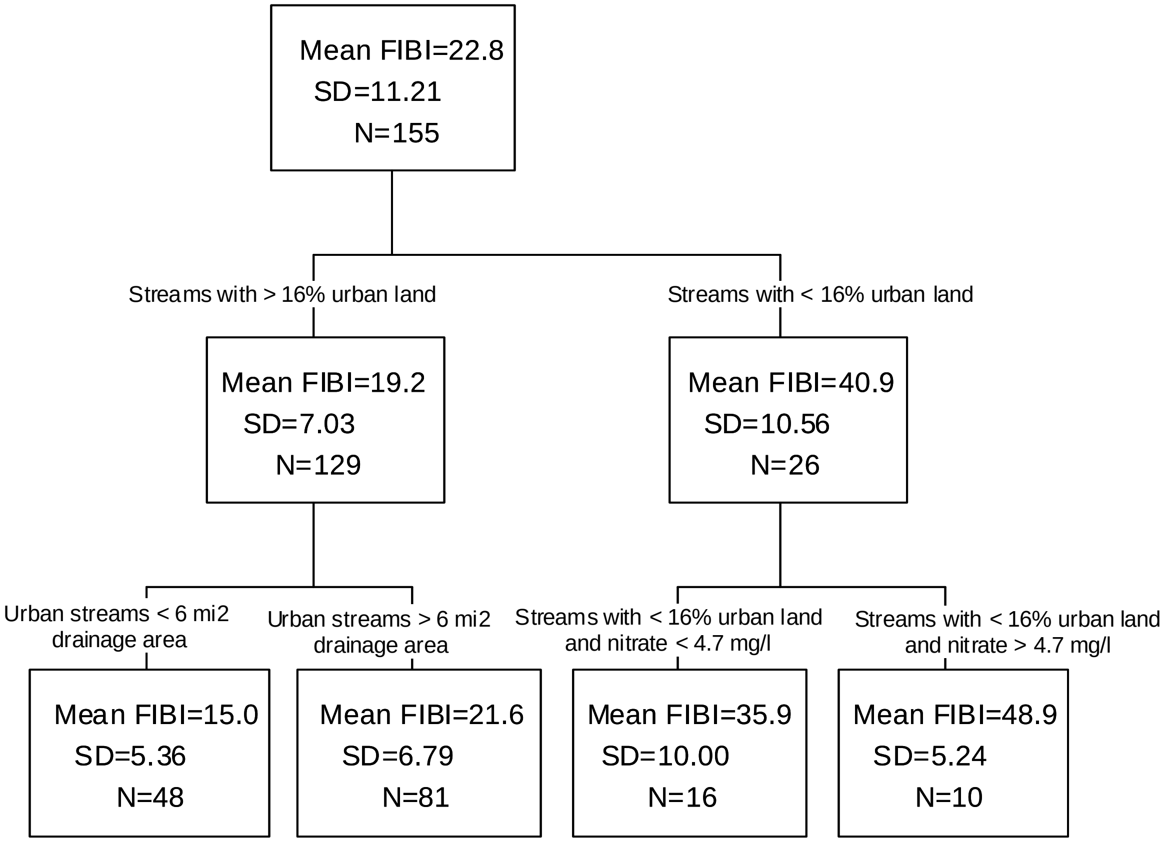


Figure 11. Classification and regression tree for fIBI scores as partitioned by environmental variables. Data include the USGS urban gradient study of Northeastern Illinois streams.

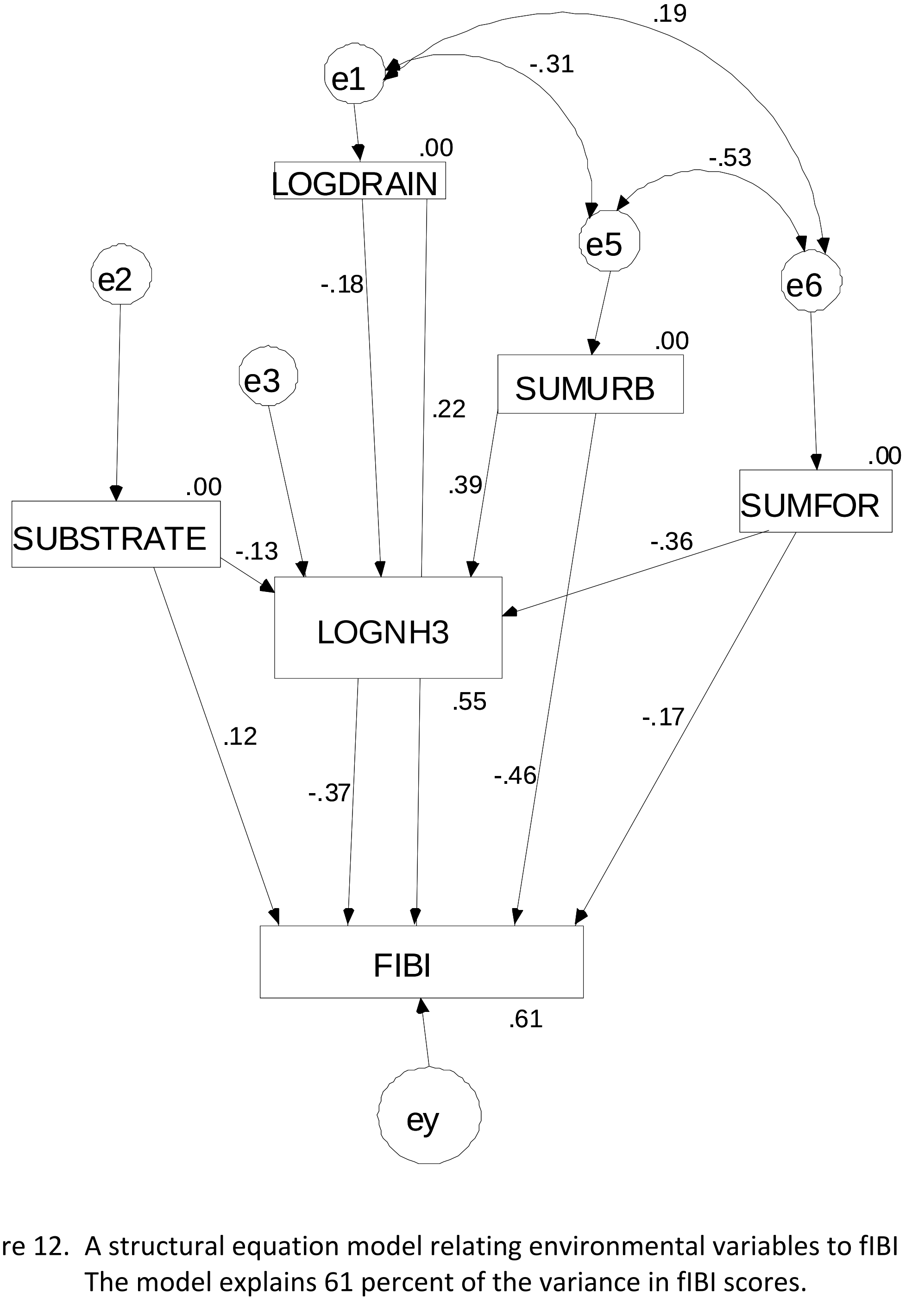


Figure 12. A structural equation model relating environmental variables to fIBI scores. The model explains 61 percent of the variance in fIBI scores.

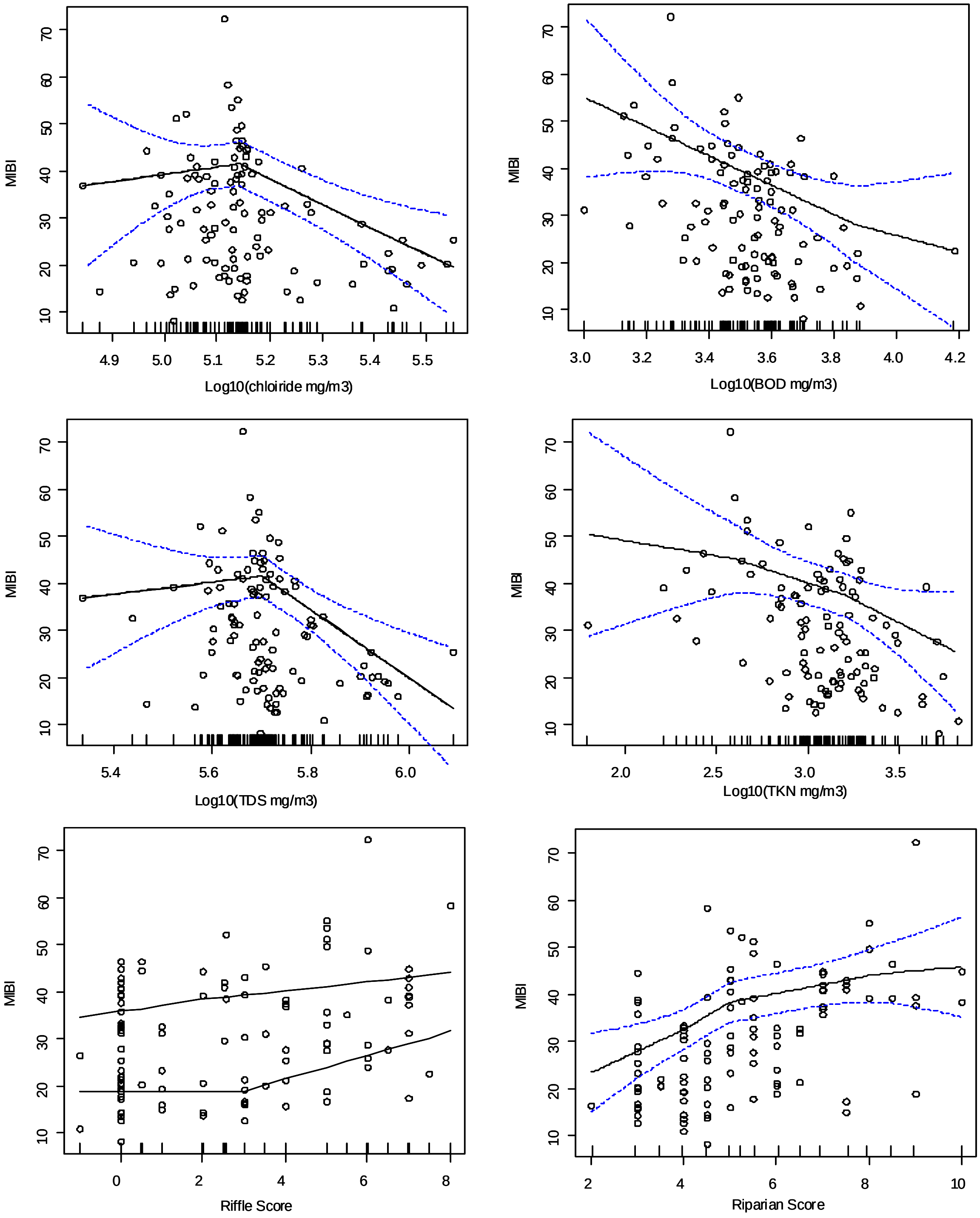


Figure 13. Thresholds in mIBI scores over environmental variables based on quantile regression at the 75th percentile (solid lines +/- 0.95 confidence interval). The plot showing the mIBI against riffle scores (lower left) shows 75th and 25th percentiles regression lines. Note that mg/m3 are equivalent to µg/l.

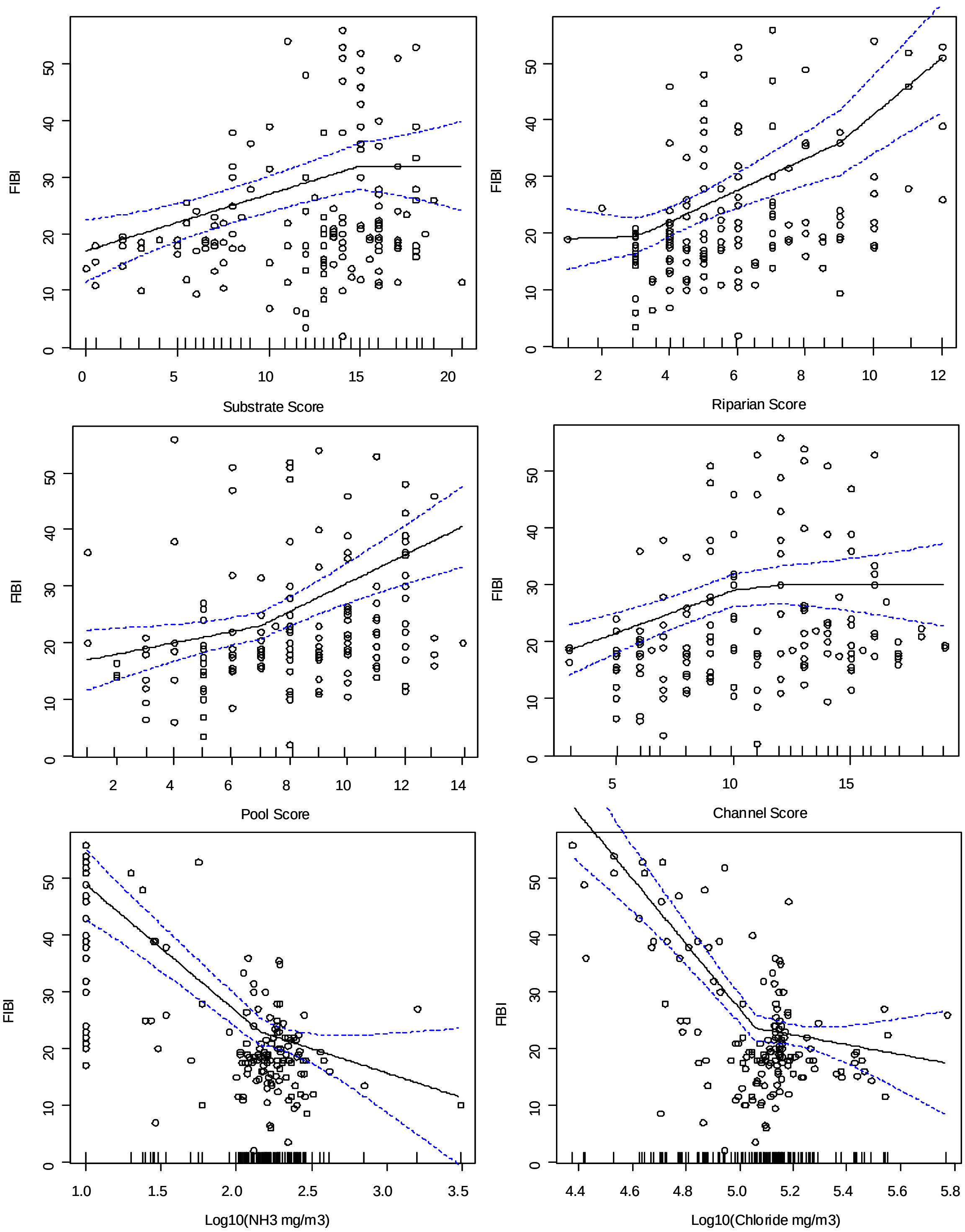
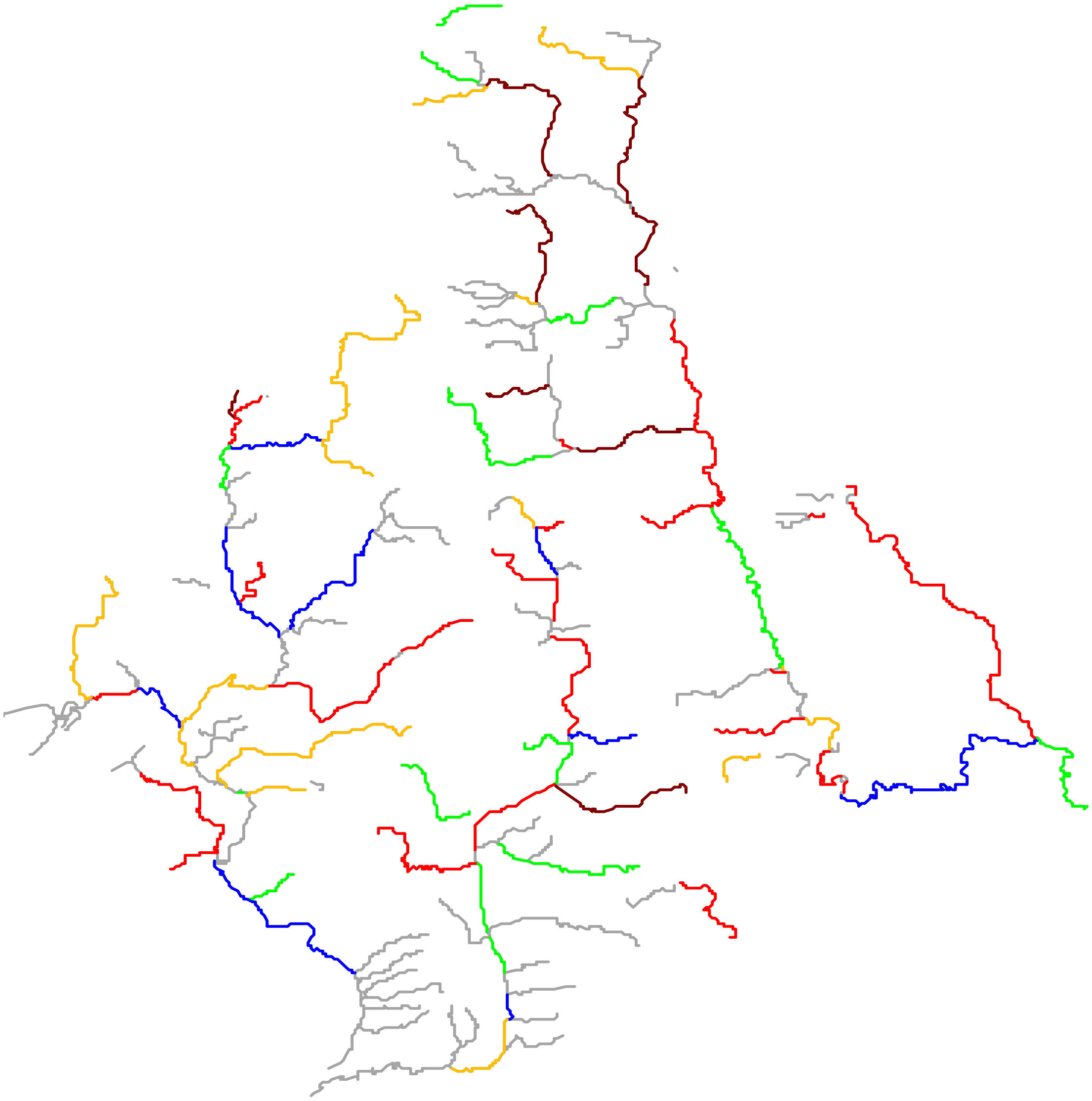


Figure 14. Thresholds in fIBI scores over environmental variables based on quantile regression at the 75th percentile (solid lines +/- 0.95 confidence interval). Note that mg/m3 are equivalent to µg/l.

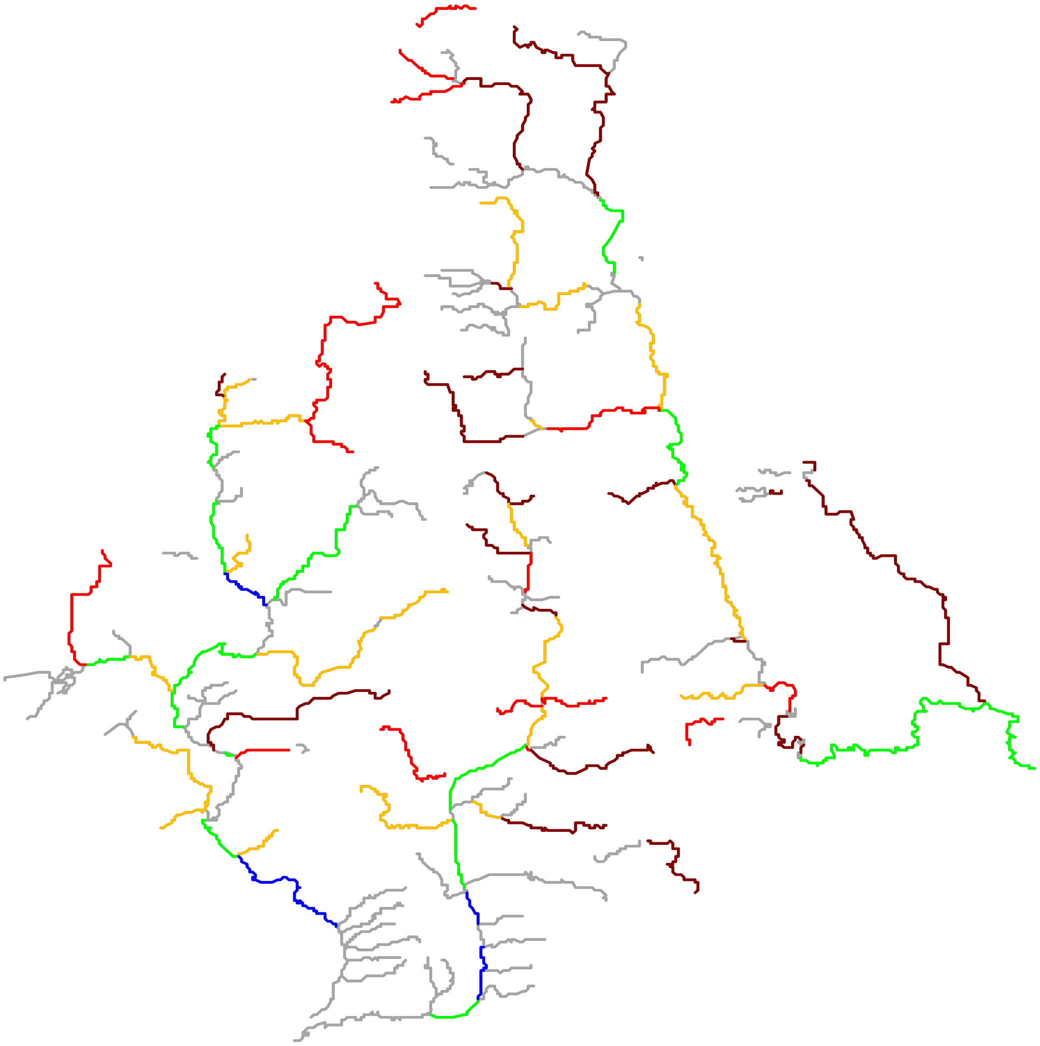
Table 3. Environmental thresholds for the most meaningful stressor parameters identified by quantile regression.

Stressor Parameter	**mIBI**	**fIBI**
Riparian Score	5	Continuous
Riffle Score	4	3
Channel Score	Continuous	10
Substrate Score	9	Continuous
Pool Score	7	7
Chloride	141 mg/l	112 mg/l
TKN	Continuous	1.0 mg/l
BOD	Continuous	Continuous
NH_3-N	Continuous	0.15 mg/l



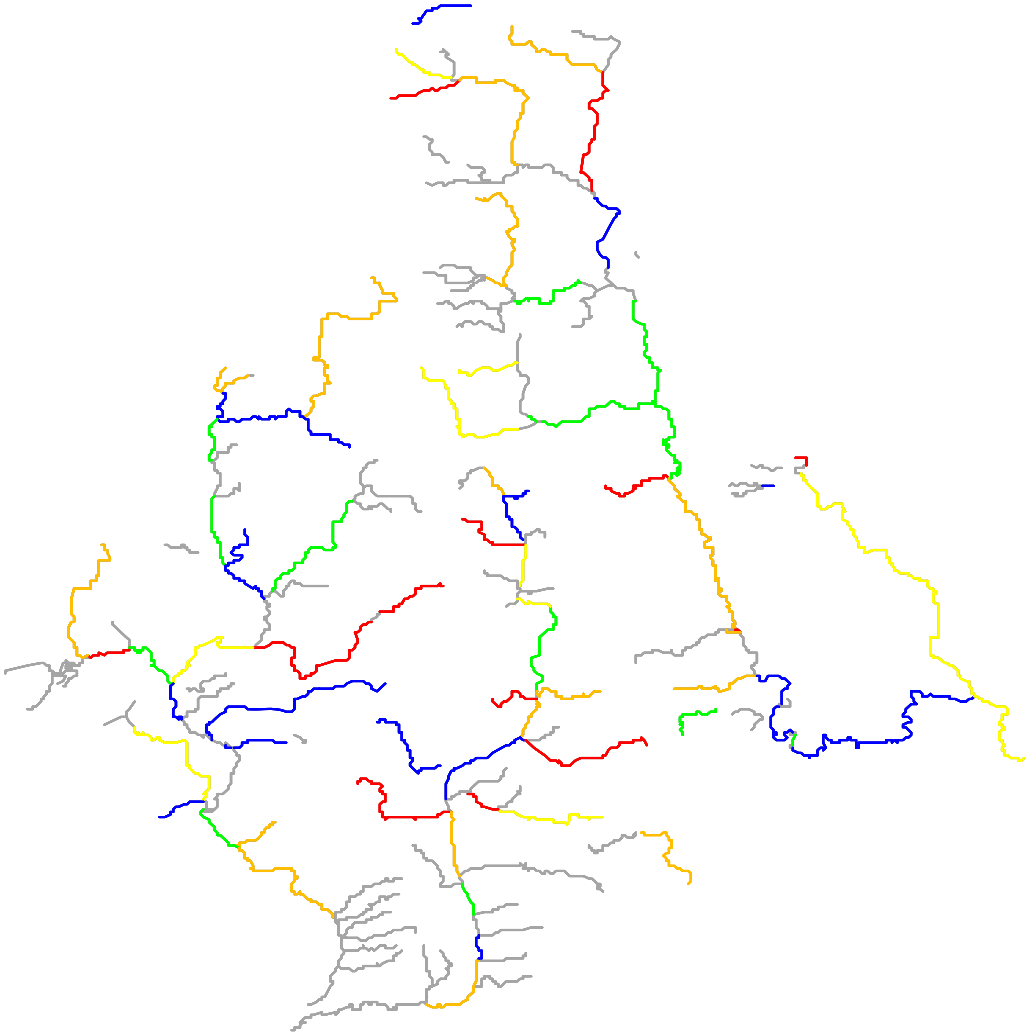
Restorability based on environmental variables; spectrum ranges from blue for most restorable to dark red for least restorable.

Figure 15. Stream segments in the DuPage River-Salt Creek study area color-coded to restorability.



Restorability based on biological departure; spectrum ranges from blue for most restorable to dark red for least restorable.

Figure 16. Stream segments in the DuPage River-Salt Creek study area color-coded to the magnitude of biological impairment (i.e., the sum of the difference from the respective IEPA "attainment" thresholds for the fIBI and mIBI).



Restorability based on amount of open space
within 500 m of the stream; spectrum ranges from
blue for most open space to dark red for least open space.

Figure 17. Stream segments in the DuPage River-Salt Creek study area color-coded to the relative amount of open space within 500 m of the stream channel.

Users Guide to the IPR

The data and information used to create the maps in Figure 15 are included in an Excel spreadsheet (IPR.xls), and a shapefile bundle (ipr_segments.zip) linking the spreadsheet to the stream segment trace. Fields in the spreadsheet contain site-specific information for water quality parameters, habitat measures, select biological attributes and biological index scores. Water quality and habitat parameters exceeding identified thresholds from the above analyses are noted with a binary flag (1 or null), and summed to gauge the magnitude of stress acting at a site, and averaged for a reach (see Figure 15). Similarly, how far fish and macroinvertebrate biological index scores depart from their respective attainment benchmarks are noted individually, and averaged at the reach level (as absolute values for plotting in Figure 16). The percent of land classified as residential, commercial, industrial, or transportation in the 500 m zone adjacent to the reach is noted, and conversely, the amount of land classes as forest, grassland, recreational, barren, or otherwise open in the adjacent 500 m is noted. These values are listed as a rough guide to segments that potentially have space for riparian restoration, stream naturalization, habitat restoration, or additional stormwater treatment (Figure 17). Taken collectively, the maps in Figures 15-17 can help prioritize segments by those where restoration projects are likely to have a relatively high probability of immediate success (i.e., those with less biological departure, fewer stressors, and more open space to work with), compared to segments where projects would necessarily have to be designed to address less tractable stressors over a longer term (i.e., stormwater in highly urbanized subcatchments).

IPR Ranking Method

A method for objectively sorting segments based on restoration potential must necessarily be directed by the data. However, no algorithm based solely on the data will yield a perfect scheme free from interpretation, but that step must occur prior to subjective interpretation. The algorithm used to prioritize the segments is quite simple, and is essentially based on percentile ranks of the number of identified stressors, magnitudes of biological departure, and the amount of open space adjacent to the reach. The basic assumption of the this scheme is that segments with relatively few stressors, modest biological impairment, and room for habitat restoration, are likely to respond faster to management than segments where the converse is true.

Dams throw an obvious wrinkle into the scheme in that dams cause severe biological and water quality impairment, and therefore the segments with dams tend to rank low in terms of prioritization based solely on water quality, physical habitat and biological departure. However, dam removal is, from an engineering standpoint, relatively straightforward, and results in immediate physical, water quality and biological benefits. This reality is incorporated in the restoration score wherein, segments with dams are moved one or two priority tiers higher based on an interpretation that included examining factors both within the reach and adjacent reaches, QHEI scores and habitat attributes, MIBI scores, FIBI scores, and water quality parameters.

The Algorithm

Scores in the field "Raw Restorability Score" are simply an enumeration of the number of proximate stressors exceeding identified thresholds. The field "Restorability Score" is an average of raw score for the segment (identified in the field "REACHCODE"). Restorability Scores are converted to ranks based on percentiles as follows:

Percentile	Rank
<10th	1
10th-25th	2
25th-50th	3
50th-75th	4
75th-90th	5
>90th	6

The ranks are stored in the field "Restorability Rank." Similarly, scores in the field "Biological Restorability" are percentile ranks of scores in the field "Biological Departure", and scores in the field "Room to Maneuver" are percentile ranks of the field "Percent Open". The three ranks are summed in the field "Total Restoration Score for Segment", and the field "Restoration Priority" lists the priority tier for each segment, adjusted for whether a dam influences the segment, as previously described. Figure 18 maps the segments by priority tiers.

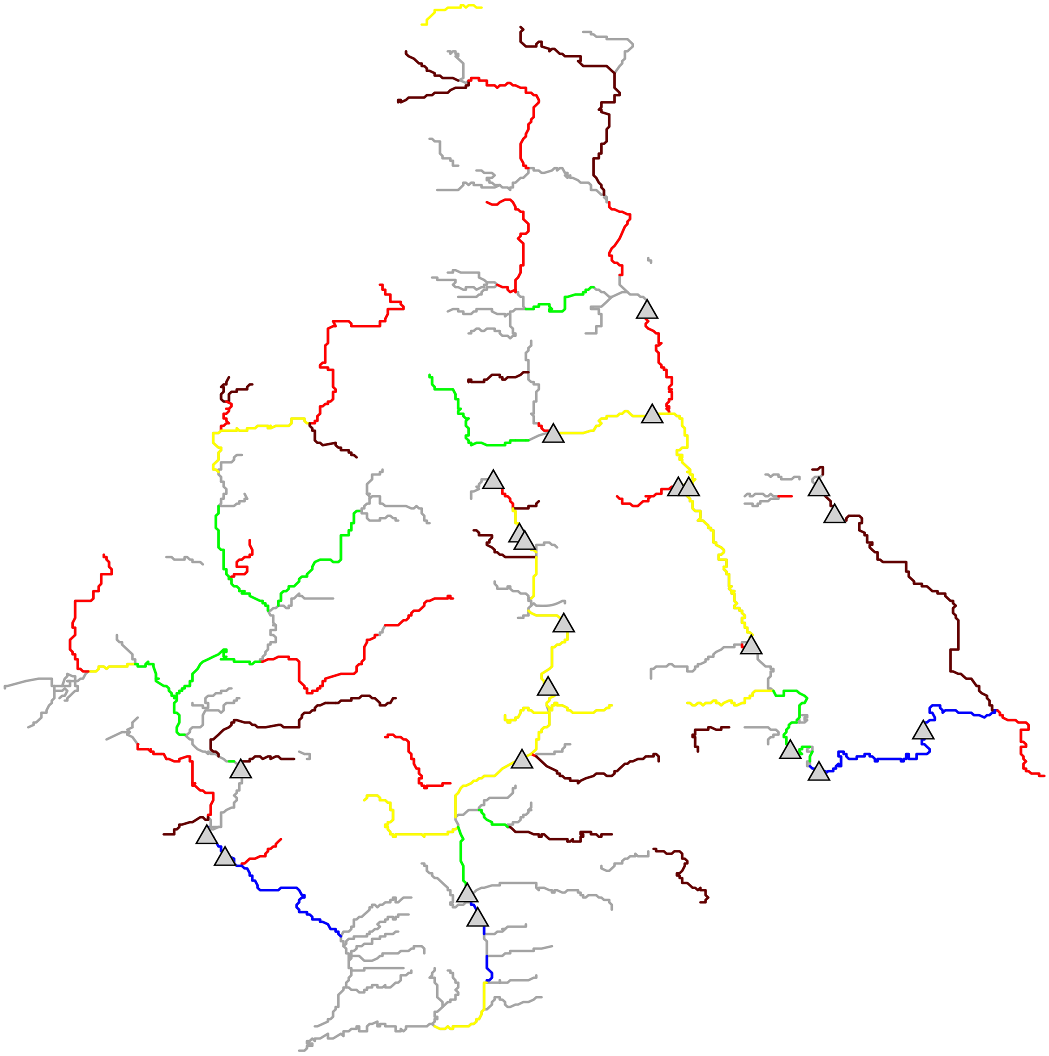
Project Objectives and Long Term Goals

Example restoration projects, albeit highly generic ones, are listed as a rough guide for interpreting and applying information in the spreadsheet. For example, the Arlington Heights Branch of Salt Creek has highly degraded physical habitat, severe biological impairment, and poor water quality. Clearly, stormwater is the overwhelming limiting factor to this reach, and the magnitude of impairment renders this a low priority reach in terms of temporal expectations for full restoration. However, improved stormwater management that addresses loadings of chloride and organic enrichment would benefit not only the reach, but the system as a whole, and projects in that vein should be given priority for the reach. Habitat restoration within the reach would also benefit the system as a whole by helping to increase assimilative capacity, but less directly than stormwater management on a temporal basis. Another example is given by Spring Brook, also a tributary of Salt Creek that is similar to Arlington Branch in terms of impairments, magnitude of biological impairment, and temporal restorability. However, unlike the Arlington Heights Branch, Spring Brook has two dams that, if removed, would have an immediate local benefit in terms of stream habitat, and wider benefit to the system in terms of reduced organic loads. The same need for stormwater management exists for this stream, especially for retrofitting the existing infrastructure away from detention/retention, and towards treatment and infiltration.

Arlington Heights Branch and Spring Brook also differ with respect to long-term outcomes. Spring Brook, by dint of being positioned further down the Salt Creek mainstem, would potentially benefit from restoration of the Salt Creek mainstem, as greater opportunity for species re-invasion exists. In this regard, the fish community in Spring Brook has the potential to move from a poor condition to a fair condition, and if water quality impairments are addressed, the macroinvertebrate assemblages should attain a good rating. Hence, the long-term goal for Spring Brook is the General Aquatic Life Use, while that for the Arlington Heights Branch is to increase the functionality of the reach for the benefit of the system as a whole. Obviously these are subjective goals that should be modified as new information becomes available.

Causes of impairment identified during the 2006/07 biosurvey and by the IEPA are listed in the field "MIBI and/or IEPA Defined Impairments." Information in the matrix can be used to readily differentiate between restoration projects that either address or fail to address the listed causes of impairment. For projects that pass the initial screening, the comparison flags and restorability rankings in the spreadsheet are not meant as absolute IF-THEN-ELSE statements, and require interpretation in light of the bioassessment report, the analyses included here, and general knowledge of how the urban milieu impacts water resources. For example, many segments have dissolved oxygen and habitat alterations listed as co-occurring causes of impairment. Dissolved oxygen data were collected with continuous monitors at several locations in the three subwatersheds (i.e., the West and East Branch DuPage, and Salt Creek), and critically low dissolved oxygen values were recorded. However, dissolved oxygen was not routinely collected from all sites during the survey, thereby precluding its addition to the stressor analyses. Similarly, polycyclic aromatic hydrocarbons (PAHs), heavy metals, and, less frequently, pesticides, from sediment samples were detected at concentrations exceeding thresholds detrimental to aquatic life at various locations throughout the watershed. Again, the spatial coverage of the sediment sampling precluded the use of the resulting data in the stressor analyses. This does not obviate the importance of those data. Rather, the resulting information should be incorporated when interpreting the matrix. By way of example, where low dissolved oxygen is caused by stagnant water pooled behind a dam, the obvious solution is to remove or lower the dam, thus improving both habitat quality and the dissolved oxygen regime. A less obvious scenario would involve a segment where dissolved oxygen is listed as an impairment, but habitat alteration is not. In such a case, habitat may not be limiting on a reach level, but specific aspects of the habitat, especially no or poorly functioning riffles, may contribute to low dissolved oxygen. Another example, one related to contaminated sediments, is the relatively high frequency of occurrence of fishes with deformities, lesions, erosions, or tumors (DELTs) observed throughout the DuPage River-Salt Creek watersheds (Figure 19). DELTS are rare in healthy fish populations, but become notably elevated when complex mixtures of stressors are present. Figure 18 shows a weak trend of increasing frequency in DELTs as one moves from west to east in the basin, coincident with the increasing trend toward higher urban density (see also Figure 8). In this sense, a project should be evaluated against all the available information in the matrix, not just the listed causes of impairment.

Using the matrix and information in Table 1 to evaluate a project where a single stressor is clearly the major limiting factor is, in contrast, fairly straightforward. The project would have to identify how it would meet most or all of the benchmarks listed in Table 3, but especially the proximate stressor(s) identified as limiting the segment. A concrete example where this might apply is for the reach of Salt Creek spanning river miles 8 through 10 (reach code 07120004000132), where organic enrichment is the leading stressor. This reach receives discharge from an active combined sewer overflow (CSO), and is immediately downstream from



Segment priority based on restoration scores and adjustments
for locations of dams; spectrum ranges from blue for 1st tier,
green 2nd tier, yellow 3rd tier, red 4th tier, dark red for 5th and 6th tiers.

Figure 18. Priority tiers based on restoration scores adjusted for presence of dams (noted as triangles in the figure).

an impoundment. Optimally both sources of enrichment should be addressed, the impoundment, because it lets nutrients fester, and the CSO because it contributes untreated (or under-treated) storm and septic water to the creek.

Another specific example, without getting too speculative and fanciful, is given by a reach of the West Branch DuPage spanning river miles 21 –23 (reach code 07120004000222) where ammonia-nitrogen and riffle and channel quality were listed as limiting factors. This reach has been historically channelized, but now flows through a continuous length of open land. Stream naturalization and restoration to this segment would not only address habitat, but would likely also address ammonia by increasing assimilative capacity.

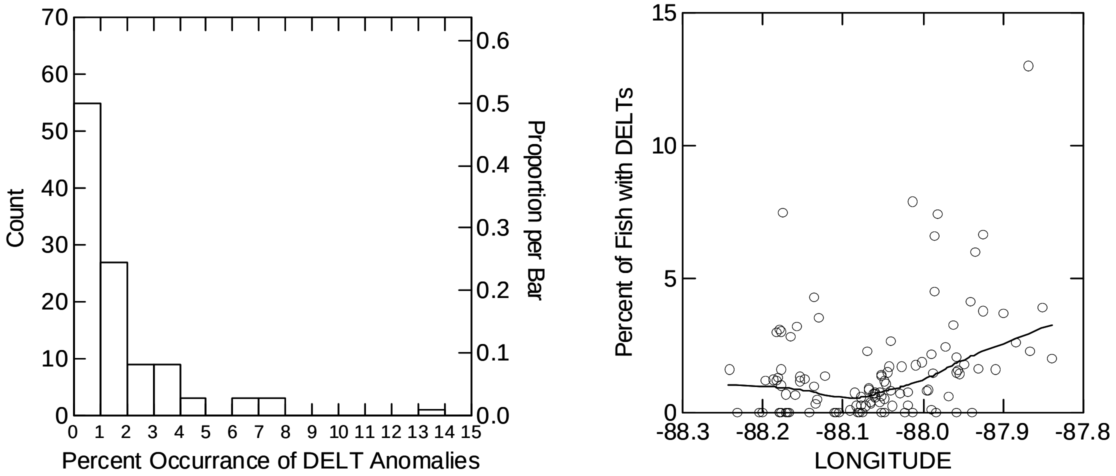


Figure 19. From left to right: frequency distribution of DELTs observed in fish samples collected during the 2006-07 DuPage-Salt Creek survey, and the percent fish at a given site with DELTs plotted by longitude.

given the highly urbanized nature of the basin, most stormwater projects should address the build-up and wash off of pollutants such as metals and PAHs from road surfaces and parking lots, organic loads and nutrients from lawns (e.g., pet wastes and fertilizers), and altered hydrology. Greater specificity is directed by the spreadsheet to address organic loadings from detention ponds, chlorides from road salt, and particulates from impervious surfaces. If a particular reach is flagged as having high TDS/chloride, some program to reduce/manage road salt is in order. For projects related to stormwater detention ponds, those should redesign the structures away from ones that contribute organic loads to the system via long retention times, toward structures that mute stormwater surges with less detention time, but incorporate passive treatment like wetlands, sand filters, or other treatment options.

Where habitat restoration is needed and there is room to maneuver, the goal of such projects should ultimately be to slow the time-of-travel, increase re-aeration, and provide a greater interface between the stream water, the periphytic microbial community, the hyporheic microbial community, and the riparian flood plain. Actions that would accomplish that goal include re-meandering straightened segments, placing riffle structures, planting trees, and improving pool depth and substrate quality (i.e., as a consequence of the preceding actions). Where space limits a full suite of options, a project may have to address a specific need like improving or adding riffle function.

Although stormwater management is an overarching need for the DuPage-Salt Creek watersheds, when project categories are grouped by stream size class, it becomes evident that most stormwater projects will be directed toward very small streams, whereas the need for habitat restoration is distributed across stream sizes (Figure 20)

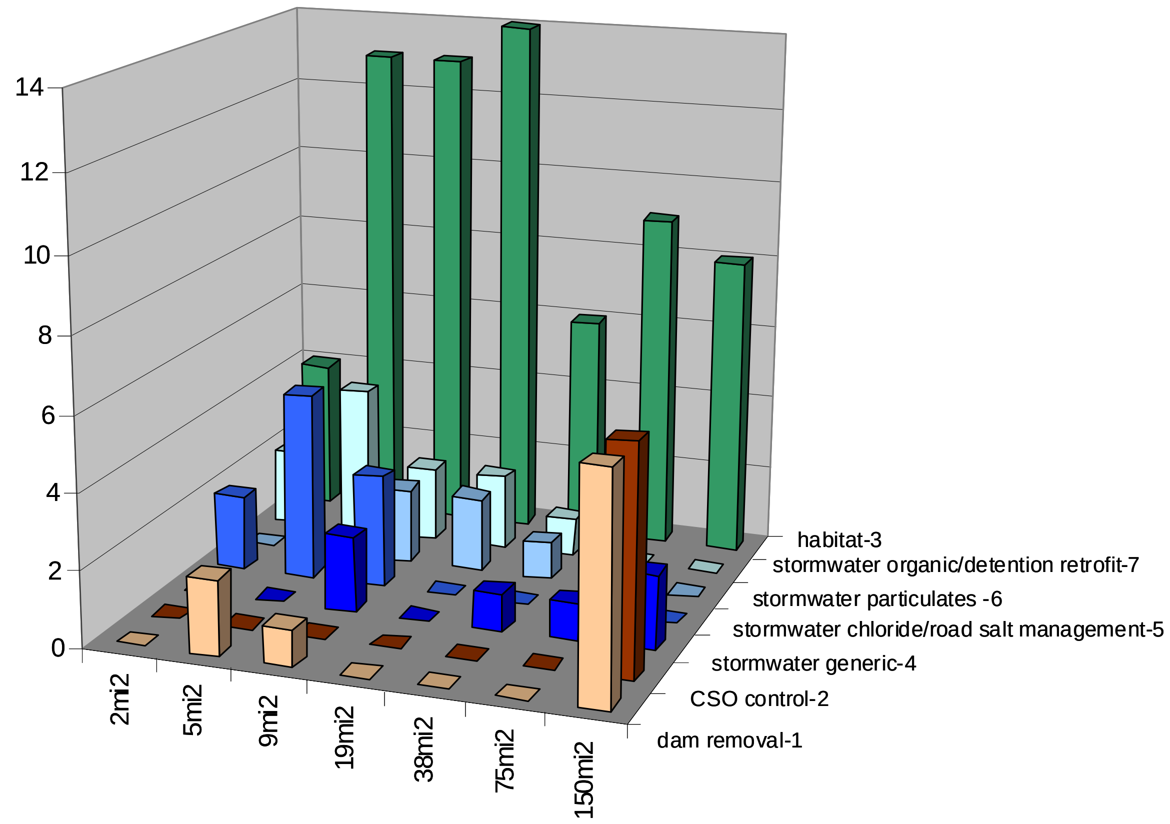


Figure 20. Frequency of restoration projects stratified by stream size class.

Where segments rank low in terms of restorability (i.e., those with multiple stressors and a high magnitude of biological departure), expectations for a restoration project would have to be scaled to the physical setting. In the case of a small, highly urbanized subcatchment, biological restoration over the short-term may not be realistic. The conceptual model in Figure 9 suggests that for these segments, a restoration goal might be improved habitat and reduced organic enrichment through better stormwater detention and treatment, with an eye toward benefiting the watershed in its entirety. Incorporating information from the matrix as a whole, in the context of the urban milieu, would also suggest that best management practices geared toward treating and reducing the build-up and wash-off of contaminants is a practical measure of watershed hygiene needed to reduce a stress that has a systemic effect. The need to consider projects at both a reach level and a watershed level is implied by the positive relationship between the number of observed proximate stressors and the magnitude of biological departure (Figure 21).

As a final note, the process listed here is iterative in that as restoration projects are brought on-line or to completion, monitoring to determine whether those projects met their goal of restoration is clearly axiomatic. Often, recovery of the macroinvertebrate assemblages precedes that of the fish by several or more years. The temptation to rely on a single indicator, either fish or macroinvertebrates, could lead to erroneous conclusions in either direction. Therefore, periodic, robust biological monitoring is recommended. Furthermore, the biological measures used for assessment must provide sufficient resolution for the types of stressors observed. As noted previously, fish showing DELT anomalies were observed with unusual regularity throughout the watershed; however, the IEPA protocol for assessing fish assemblages does not call for recording DELTs. It is strongly recommended here that DELTs be recorded in future biological assessments for the purposes of trend analysis, and for monitoring current conditions (i.e., has improvement been observed in parts or all of the watershed, and are there still “hot spots”).

The process is also iterative as accrual of new information changes knowledge of the system. Although the relationship between urbanization and biological integrity has been well documented in the literature, and a generalized cause-effect model relating urban stressors to biological integrity is well established, ambiguity exists over the relative contribution of stressors to impairment. For example, an urban gradient study of the Chicago metropolitan area (Fitzpatrick et al. 2005, Harris et al. 2005) found no relationship between riparian width and fIBI scores. In contrast, riparian width was positively associated with both mIBI and fIBI scores (see Figures 13 and 14) in this study. The difference in results is mostly likely related to artifacts of study design. In the Fitzpatrick et al. (2005) study, the gradient of land use was extended away from urban by including streams in agricultural settings. Clearly, any moderating effect of riparian buffers would be overwhelmed, in a statistical sense, when comparing agricultural streams to urban streams, but not, apparently, when looking within homogeneous uses. The moderating effect of riparian buffers on urban streams has been documented (Steedman 1988), but that effect is compromised by the number of direct stormwater connections to the stream (Walsh 2005). The scope of the 2006-07 study of the DuPage River-Salt Creek watersheds did not include documenting the direct number of stormwater connections to stream segments, nor did it include source identification of sediment PAH contamination. The point being that as restoration unfolds, the relative contribution of the various stressors, be they those identified here or ones awaiting identification (i.e., direct stormwater connections, emerging contaminants, endocrine mimics, lawn chemicals, spills, illegal dumping, illicit sewer connections, etc.) may become more apparent.

This, of course, does not imply that managing for restoration need wait on perfect knowledge of the system. The process used here was robust and statistically rigorous, and therefore provides a high degree of confidence that the identified stressors are, indeed, proximate, amenable to management, and likely to result in significant biological improvement if acted upon.

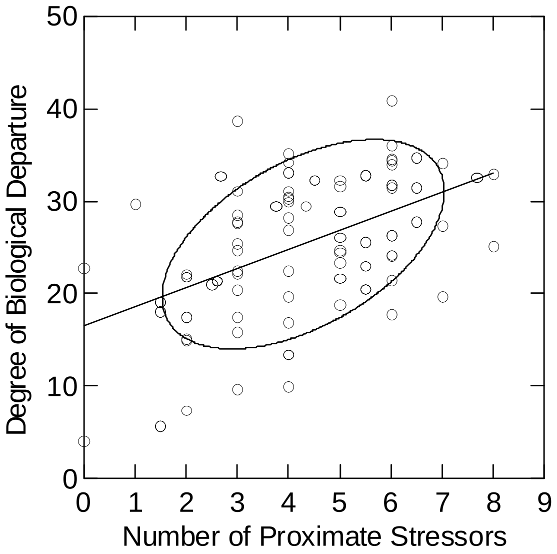


Figure 21. Degree of biological departure for a stream segment plotted against the average number of proximate stressors affecting the segment (coefficient of correlation = 0.5045).

Table 4. Project categories and brief description of what the projects should accomplish.

Project Category	Project Objective and Notes
Dam Removal	Dam removal provides immediate benefits by improving the dissolved oxygen regime, thus minimizing the frequency critically low events, and reducing the frequency of conversion of oxidized nitrogen to reduced forms. Also directly improves the stream physical habitat.
CSO control	CSO control should be aimed at reducing the frequency of events, magnitude of discharges, and especially capture and best possible treatment of the first flush of storm events.
Habitat Restoration	Where the habitat is poor and there is room to maneuver, put in meanders, riffle structures, plant trees, and improve pool depth with an eye toward slowing the time-of-travel, increasing re-aeration, and providing a greater interface between the stream water, the periphytic microbial community, the hyporheic microbial community, and the riparian flood plain. Specific aspects of habitat restoration applicable to a given reach can be drawn by examining the matrix of habitat attributes appearing in Table 9 of the DuPage-Salt Creek Bioassessment Report, and the IPS spreadsheet.
Stormwater Management	The highly urbanized nature of the basin calls for a generic, prescriptive approach to stormwater management broadly applicable to all waters. Projects in this vein should address the build-up and wash off of pollutants such as metals and PAHs from road surfaces, organic and nutrient loads from lawns, and altered hydrology.
Chlorides	Projects aimed at reducing loadings and impacts of de-icing are directed toward specific stream reaches where chloride concentrations were notably high.
Particulates	This subcategory of stormwater management was added to help direct more specific action where available data indicated suspended solids and metals were elevated.
Detention Redesign	Redesign detention ponds away from structures that contribute organic loads and ammonia (via cooking algae and/or denitrification due to low dissolved oxygen), toward structures that mute stormwater surges with less detention time, but incorporate passive treatment like wetlands, sand filters, or other options that someone versed in engineering such things would be better able to list and describe.

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Appendix A. Development of a BCG for Fish Assemblages for Northeast Illinois Streams and Development of a Historical Fish Community

Introduction

The ability to predict the restorability of an aquatic assemblage in a stream and watershed can be enhanced by a detailed knowledge of the ultimate potential or historical assemblage that could exist and how changes to streams and watersheds limit reasonable or “feasible” recovery to these endpoints. The US EPA has created a Biological Condition Gradient (BCG) concept that describes how ecological attributes change in response to increasing levels of human disturbance (Davies and Jackson 2006). Our goal here is the describe the natural anchor or biological potential for streams in the Dupage River system and to quantify how the predominant stressors in this watershed can limit aquatic assemblage recovery, and as a consequence inform the choice of various restoration options within the streams of these watersheds. The approach we are taking here is similar to one we conducted for the mainstem Wabash River (Rankin et al. 2009), but modified for the small streams of the Dupage River and Salt Creek watersheds. In this effort, because of resource constraints we focused on fish assemblages, but a similar process can be developed for macroinvertebrate and mussel assemblages.

The BCG

The Biological Condition Gradient is a conceptual model that provides a narrative description to changes in aquatic assemblages (e.g., fish and macroinvertebrates) with increasing degradation and stress (Table 1). US EPA vetted this approach over the past decade with aquatic biologists throughout the US (Davies and Jackson 2006). The BCG is composed of ten key biological attributes of natural aquatic systems. The general attributes are applicable throughout the country; however the specific form and changes of the attributes with increasing stress (pollution, habitat disturbance) are quantified uniquely for different ecological regions. The ten attributes are listed in Table 2. Most, but not all are directly measurable with existing monitoring data that is available for the Dupage River. The gradient of biological condition (y-axis) has been divided into 6 tiers of condition that reflect categories

Table 1. Summary of the expected biological changes that would occur along a Biological Condition Gradient for the Dupage River and Salt Creek watersheds

Tier	Description
1	Natural or native condition
2	Minimal changes in structure of the biotic community and minimal changes in ecosystem function
3	Evident changes in structure of the biotic community and minimal changes in ecosystem function
4	Moderate changes in structure of the biotic community with minimal changes in ecosystem function
5	Major changes in structure of the biotic community and moderate changes in ecosystem function
6	Severe changes in structure of the biotic community and major loss of ecosystem function

that biologists agreed could be readily distinguished by robust monitoring data. The gradient of biological condition also infers the existence of one or more concomitant stressor gradients (x-axis) that conceptually is summarized as a "generalized" stressor gradient (see Figure 1). In the work we will do here we will examine a number of specific stressor gradients that we will construct from monitoring data (e.g., chemical stressors, habitat) or other sources such as land use and hydrology data. The general definitions of biological changes that occur over the 6 tiers of the BCG are listed in Table 1.

Table 2. List of the ecological attributes of the BCG.

No.	Ecological Attributes
I	Historically documented, sensitive, long-lived or regionally endemic taxa
II	Highly sensitive taxa
III	Sensitive & common taxa
IV	Taxa of intermediate tolerance
V	Tolerant taxa
VI	Non-native or intentionally introduced taxa
VII	Organism Condition
VIII	Ecosystem Functions
IX	Spatial and temporal extent of detrimental effects
X	Ecosystem connectance

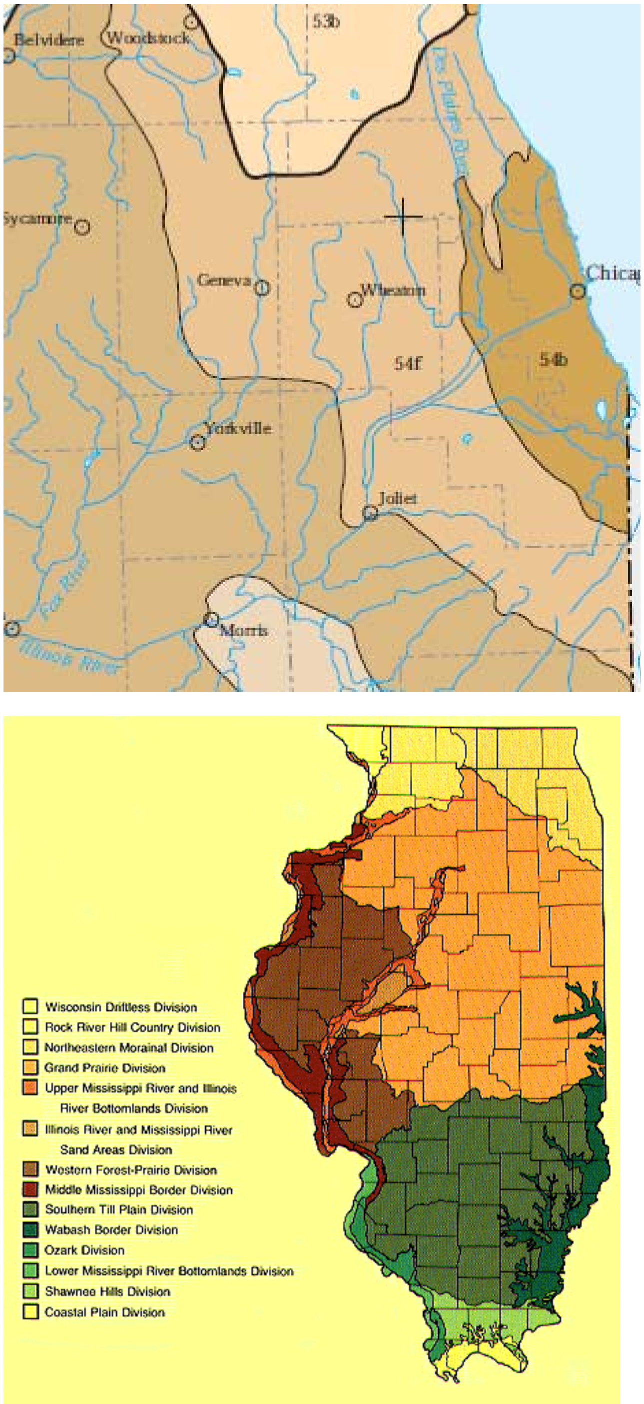

Figure 1. Maps illustrating the U.S. EPA level 3 ecoregions (top) and Illinois Natural Divisions that encompass the Dupage River and Salt Creek watersheds.

The Reference Site Concept

Recently (Stoddard et al. 2006) encapsulated efforts over the past 20 years to identify regional reference conditions and to provide a way to quantify tiers of ecological condition that would allow explicit, but nationally comparable biological goals to be developed for streams and rivers. The work of Stoddard et al. (2006) provides some standard definitions of reference site

Table 3. Names and descriptions of reference conditions of interest to the Wabash River study (from Stoddard et al 2006) and links to the tiers of the BCG (Davies and Jackson 2006).

Reference Type	BCG Tier(s)	Description
Minimally Disturbed Condition (MDC);	**1**	MDC describes the condition of rivers with minimal human impacts and according to Stoddard et al. (2006) would represent a definition of Biological Integrity. This is the anchor we are attempting to describe with our analysis and extrapolation of historical conditions and is not a feasible goal for most Midwestern streams. In projecting improvement of existing conditions it will help in the definition of what might be BAC given various pathways of restoration in the Dupage watershed.
Historical Condition (HC)	**1-2**	In this paper we use a pre-intensive agriculture definition for the historical condition based on the historical accounts of northeastern based on early settlement. Stoddard et al. (2006) identifies this as the early 18th century in the Eastern U.S. and would extend later in the 18th century in Illinois and the Midwest.
Least Disturbed Condition (LDC) and Best Attainable Conditions (BAC)	**2-4**	LDC represents sites with the least amount of anthropogenic disturbance. In many Midwest watersheds, especially where drainage and wetland removal was widespread, it can be argued that this is a relatively low bar or goal. Nevertheless, where a gradient of local impacts exist as they do in the Dupage watershed, some sites with relative intact habitat can be defined as LDC, especially in the free-flowing, less urbanized portions of the watershed. Reference sites from neighboring watersheds have also been selected to provide a stronger gradient of LDC sites.
Best Attainable Condition (BAC)	**2-4**	BAC represents what would be the best attainable conditions given either rehabilitation of Dupage River streams to the best LDC condition available today (likely from local habitat and riparian restoration) or rehabilitation to some condition between LDC and MDC if headwater watershed impacts could be reduced. Again full MDC or HC are not likely an appropriate goal given the economic uses of the landscape in the Dupage River watershed, however, development of what these BAC ("feasibly restorable") conditions could be is dependent on our extrapolation of HC conditions for Dupage River streams
Moderately Impaired[1] Conditions (MIC)	**5**	MIC represents sites that have local or upstream sources of stress that prevent assemblages from attaining a LDC for Dupage River streams. These sites however do not have evidence of severe toxic responses or severe losses of diversity, however they typically have no intolerants, small number of sensitive species and are dominated by species of intermediate or high tolerance
Severely Impaired Conditions (SIC)	**6-7**	SIC represents conditions at sites that suffer from severe toxic or extreme habitat losses that result in extensive reductions in diversity and near complete loss of even species of intermediate sensitivity. At the extreme, tolerant species may be reduced. Such sites were characteristic of many sites prior to the implementation of the CWA.

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[1] For this analysis impaired is relative to the CWA interim fishable goal which is typically approximated by a biological target score (e.g., IBI of 36 in Indiana) or warmwater biocriteria number where tiered uses exist (e.g., Ohio). Higher tiers could be considered impaired for high aquatic life use tiers (e.g., EWH, Tier 2-3) or to a Biological Integrity Goal (Tier 1-2).

categories that have developed over the past 20 years. We will use the reference site concept, implemented through our BCG development, to help define the historical condition and the current potential or restorability of streams from their current condition. Stoddard et al. (2006) summarize the gradient of reference conditions that can be used in the management of flowing waters (Table 3). For most lower-Midwestern streams and rivers it is unlikely that few if any streams could be classified, according to the definitions of the BCG, as having Minimally Disturbed Conditions (MDC). Existing conditions, depending on the stream and setting would likely be described as Least Disturbed Conditions (LDC) at best and more typically as Best Available Conditions (BAC). Describing the Historical Condition (HC) and extrapolating, from historical descriptions to approximate MDC can be used to determine the potential to shift small stream assemblages towards these conditions. For the streams of the Dupage River and Salt Creek watersheds we consider the best of the available reaches to be BAC and will use the BCG exercise described below to guide us in establishing and quantifying what historical conditions may have approximated. The goal of this exercise is not to set a pristine or natural goal for the aquatic fauna of these streams, but rather to create data to derive a trajectory between existing and historical conditions. By projecting what would be feasible in terms of stressor reduction (rehabilitation) we can be predictive in terms of what biological goals are attainable for the streams of the Dupage River and Salt Creek watersheds given an urban and suburban template that is not going to change. Water and biological quality can definitely be improved in such watersheds; however quantifying realistic expectations will be an important challenge.

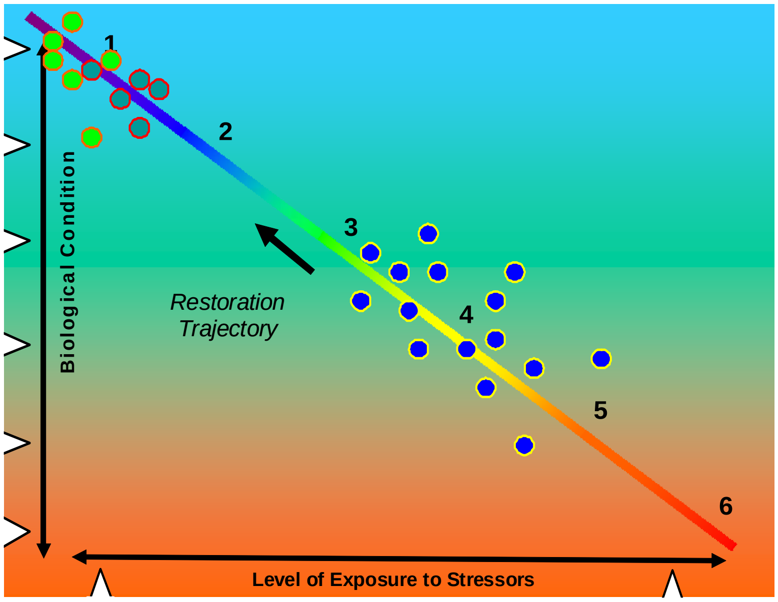

Figure 2. *U.S. EPA hypothetical plot of biological conditon (y-axis) vs. a stressor gradient (x-axis) (Modified from U.S. EPA 2005). On this graph we have superimposed points presenting existing conditions in the Wabash River mainstem (blue points) and two groups of points representing pre-settlement (green points) and post-settlement conditions (grey points).*

Extrapolation of Fish Assemblages to Pristine and Pre-Settlement Historical Conditions in the Dupage River and Salt Creek Watersheds

One of our goals is to understand the historical fish assemblage condition and biodiversity in the streams of the Dupage River and Salt Creek watersheds to provide an endpoint or anchor point for extrapolating between existing conditions. This concept is illustrated in Figure 2 which was modified from one produced by U.S. EPA. The dark blue points represent the existing conditions in nearby reference sites (points to center left) and streams of the Dupage River and Salt Creek watershed (points towards right) along an abstract “stressor gradient” along the x-axis. This stressor gradient represents the cumulative stressor “load” that influences the biota of the stream in the watersheds. The green and grey points reflect hypothetical pre-settlement and immediate post-settlement conditions in these streams. Because of the great landscape changes that have occurred in these watersheds a return to these conditions are not realistic or even desirable given what would need to be changed on the landscape to attain such goals. They do however provide a powerful conceptual connection or trajectory with current conditions and where axes can be quantified a tangible connection for prediction. After we create our synthetic historical fish assemblage, we will plot that data along with existing reference sites and current Dupage and Salt Creek sites on a similar graph.

One goal of this work is to generate a "synthetic," computer derived estimate of historical condition (e.g., species populations) and then to use this assemblage to estimate or "infer" environmental conditions at these sites. We generated species-specific weighted stressor values (WSVs) and taxa indicator values (TIVs) for each major stressor (see methods below) as parts of other research projects (Rankin et al., in review) and then used the biological data to estimate the environmental conditions (e.g., stressors) at sites based on species presence weighted by their abundances. For existing data such associations are key to the stressor identification work done in the main body of the report. WSVs and TIVs, along with multivariate statistical approaches, were used as a tool to diagnose potential causes of impairment. For the historical assemblages we derived biologically inferred stressor estimate by "backcasting" data to represent a hypothetic stressor environment during historical periods and provide a trajectory of stressors that can be connected to existing conditions. For species not represented in the database we chose stressor values that likely existed when they were distributed more commonly across the landscape. Others may now be absent in the Dupage, but still common in less stressed areas of their range and represented in our database.

Stream Classification: Stream Size and Stream Gradient and Historical Conditions

The landscape of the Dupage River watershed has changed substantially over the past two hundred years. Changes were summarized by Illinois DNR in 2001 as part of their Critical Trends Assessment Program (Illinois DNR 2001):

> "Prior to settlement around 1820, 86.5% (206,270 acres) of the Dupage River area was prairie, said to be among the finest and the most productive prairie in the state. Today only 98 acres (0.04% of the basin) of undegraded, high quality prairie survive here. Forest covered about 13.5% (32,192 acres) of the land in 1820. It was concentrated on the slopes, ravines and bottomlands associated with the Dupage River, and in protected areas associated with moraines. Today 11% (26,793 acres) of the area remains forested (83% of the original amount). In the early nineteenth century wetlands covered far more of the area than they do today - 30-39% (71,539-93,000 acres) then compared to 4.5% (10,695 acres) now, slightly higher than the statewide total of 3.2%. Surviving wetlands tend to be concentrated along the river and stream corridors and in the northwest third of the basin. None are designated as high-quality."

From a natural stream classification perspective, the extent of historical wetlands suggests that stream gradient is an important natural classification feature and we will note historical species that had an affiliation with low gradient or "wetland" stream types. Such streams may have different restorability endpoints and restoration options than higher gradient streams in these watersheds. Sangunett (2005) summarized the historical form of the streams of the Grand Prairie (that includes part of the Dupage River) and how these streams where changed by settlement:

> The presettlement landform had meandering streams with large intervening areas that lacked defined drainage courses. The later resulted in marshes and wet and tallgrass prairie. On the prairie, small streams were usually lined by grasses and shrubs, while larger streams provided firebreaks, allowing for the development of a gallery forest (Larimore and Bayley 1996, Wiley et al. 1990). The rich prairie soils enticed settlers to plow the sod in spite of the wetness. To improve drainage, farmers straightened existing streams, shortening their length in some cases, while ditching added streams where none had existed (Wiley et al. 1990). In addition to creating ditches, farmers also tiled their fields, lowering the water table. Over the past 200 years, the most significant change in land cover in the Grand Prairie has been the conversion of prairie to crop land… Surprisingly, forest, and open water have increased over this period, but this is not generally thought of as an improvement, as the quality of these systems is degraded (IDENR 1994).

Stream size is another important natural classification feature that is common to most Warmwater streams that have been studied. The expected biological assemblages in streams change with stream size, so we are noting the expected size of stream we expect each species to occur in: headwater streams (<20 sq mi), larger "wadeable" streams (~ 20- 300 sq mi) and rivers, which are generally greater than about 300 sq mi in size.

Historical Fish Species in the Dupage River and Salt Creek Watersheds

A list of the historical, recent, and present day fish species collected from the Dupage River and Salt Creek drainages are listed in Table 4. Historical sources were primarily the Fishes of Illinois (Smith 1979) and distribution maps from the Illinois Natural History Survey web site.[2] The list of endangered fish and aquatic invertebrates that inhabit streams are listed in Tables 5 and 6, respectively. The Wisconsian glaciations had a strong effect on the fish species that reinvaded the parts of Illinois that include the Dupage River watershed. This was summarized in a recent analysis by USGS (2006):

> *One of the likely* consequences *of the Wisconsinan glaciation is that fishes that prefer small, clear streams were favored during the southern dispersal. Because water became tied up in glacial ice, rainfall declined, and the Mississippi River and its tributaries became less turbid, upland and clear-water species were able to utilize the tributaries for dispersal and refuge (Burr and Page, 1986). The pool of species available for reinvading the glaciated regions, thus, included many fishes that were adapted to small, clear streams. This fact suggests that the presettlement fish assemblage of the UIRB may have been particularly sensitive to increases in turbidity and sedimentation. Another consequence of the Pleistocene glaciation is that the aquatic fauna of the upper Midwestern United States, including the UIRB, consists of*

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[2] http://www.inhs.uiuc.edu/animals_plants/fish/ilfish.html

Table 4. List of fish species collected in historical collections or in surveys from 1970s or from more recent surveys including 2006-2009.					
Species name	Historical (Pre-1979)	Expected Stream Size	1970s	Present	BCG Attribute
Sea lamprey	X	-e			
Central mudminnow	X	H, W	S	S, D	5
Gizzard shad	X	L	D	S, D	4
Grass Pickerel	X	H, W	D	D	4
Northern pike	X	W, L		S,	3
Common carp	X	-e	S, D	S, D	6
Goldfish	X	-e	S, D	S, D	6
Golden shiner	X	W, L	S, D	S, D	5
Creek chub	X	H, W	S, D	S, D	5
Hornyhead chub	X	H, W	D	S, D	3
Southern redbelly dace	X	H		D	3
Emerald shiner	X	W, L	D	S, D	4
Rosyface shiner	X	W			2
Striped shiner	X	W	D		3
Common shiner	X	W	D	D	4
Bigmouth shiner	X	H, W	S, D	S, D	4
Red Shiner	-[a]	W, L	D		
Spotfin shiner	X	W	D	S, D	4
Sand shiner	X	H, W	D	S, D	3
Mimic shiner	M	W, L			2
Redfin shiner	X	W	D		4
Spottail shiner	M	L			4
Pallid shiner	M	L			2
Blacknose shiner	X	H, W			1
Pugnose shiner	-[a]				1
Suckermouth minnow	X	W, L	D		4
Bluntnose minnow	X	H, W, L	S, D	S	5
Fathead minnow	X	H, W	S, D	S	5
Bullhead minnow	M	L		D	3
Central stoneroller	X	H, W, L	D	D	4
Largescale stoneroller	X	H, W, L		D	3
Quillback carpsucker	X	W, L		D	4
River carpsucker	M	L		D	4
Golden redhorse	X	W, L		D	3
Black redhorse	M	W, L	D		2
Silver redhorse	X	W, L			3
Shorthead redhorse	X	W, L		D	3
River redhorse	M	W, L			2
Greater redhorse	X	L			1
Northern hog sucker	X	W, L	D		3
White sucker	X	H, W	S, D	S, D	5
Spotted sucker	M	W, L		S	3
Creek chubsucker					2

Table 4 (continued).

Flathead catfish	M	L		D	3
Channel catfish	X	W, L		S, D	4
Black bullhead	X	W	S, D	S, D	4
Brown bullhead		W		D	4
Yellow bullhead	X	W		S, D	5
Stonecat	X	W	D	D	3
Tadpole madtom	X	W	D	D	4
Slender madtom					2
Pirate perch	-[a]	W			
Blackstripe topminnow	X	H, W	D	S, D	4
Western mosquitofish	X	H, W		S, D	4
Brook silverside	M[a]	W, L		S	4
White bass	M	L		S	4
Yellow bass	M	L		S, D	2
Green sunfish	X	H, W, L	S, D	S, D	5
Pumpkinseed sunfish	X	W, L	S, D	S, D	4
Bluegill	X	W, L	S, D	S, D	5
Longear sunfish	X	W, L	D	D	3
Orangespotted sunfish	X	W, L	D	S, D	4
Redear sunfish		W, L		S, D	6
Warmouth	M	W, L	D		3
Rockbass	X	W, L	D	S, D	3
Smallmouth bass	X	W, L	D	D	3
Largemouth bass	X	W, L	S, D	S, D	4
White crappie	M	W, L		D	4
Black crappie	X	W, L	S, D	S, D	4
Walleye	M	L		S, D	4
Yellow perch	M	W, L		S	4
Iowa darter	X	W			1
Slenderhead darter		W, L	D		2
Blackside darter	X	W			3
Logperch	X	W			3
Johnny darter	X	H, W	D	S, D	4
Fantail darter	X	H, W			4
Orangethroat darter	-[a]	H, W			4
Banded darter	-[a]	W	D		3
Mud darter	X	W, L			
Least darter	X	H, W			3
Freshwater drum	X	L, W			4
Brook stickleback	-[a]	H, W			4

[a] Collected in adjacent watersheds
[e] Exotic species
X – Collected in historical samples
M – Collected in historical samples at mouth in Illinois River
H – Headwater streams < 20 sq mi, W – Wadeable streams 20-~300 sq mi; Larger rivers > 300 sq mi
W – Wadeable streams > 20 - ~ 300 sq mi
L – Non wadeable streams > 300 sq mi
S – Recently collected from Salt Creek watershed
D – Recently collected from Dupage River watershed

Table 5. Illinois endangered and threatened fish species (IESPB 2009). Species with historical occurrences in the Dupage River and Salt Creek watersheds or nearby in the Illinois River or Des Plaines River or in closely adjacent watersheds are bold.

Endangered Species		Threatened Species	
Acipenser fulvescens	Lake Sturgeon	*Ammocrypta pellucidum*	Eastern Sand Darter
Ammocrypta clarum	Western Sand Darter	*Catostomus catostomus*	Longnose Sucker
Etheostoma camurum	Bluebreast Darter	*Coregonus artedi*	Cisco
Etheostoma histrio	Harlequin Darter	*Erimystax x-punctatus*	Gravel Chub
Hybognathus hayi	Cypress Minnow	***Etheostoma exile***	**Iowa Darter**
Hybopsis amblops	Bigeye Chub	*Fundulus diaphanus*	Banded Killifish
Hybopsis amnis	**Pallid Shiner**	***Fundulus dispar***	**Starhead Topminnow**
Acipenser fulvescens	Lake Sturgeon	*Lampetra aepyptera*	Least Brook Lamprey
Ichthyomyzon fossor	Northern Brook Lamprey	*Lepomis symmetricus*	Bantam Sunfish
Lepomis miniatus	Redspotted Sunfish	***Moxostoma carinatum***	**River Redhorse**
Macrhybopsis gelida	Sturgeon Chub	*Notropis chalybaeus*	Ironcolor Shiner
Moxostoma valenciennesi	**Greater Redhorse**	***Notropis heterodon***	**Blackchin Shiner**
Nocomis micropogon	River Chub		
Notropis anogenus	Pugnose Shiner		
Notropis boops	Bigeye Shiner		
Notropis heterolepis	Blacknose Shiner		
Notropis maculatus	Taillight Shiner		
Notropis texanus	Weed Shiner		
Noturus stigmosus	Northern Madtom		
*Scaphirhynchus albus***	Pallid Sturgeon		

Table 6. Illinois endangered and threatened aquatic invertebrate species that may occur in flowing water (IESPB 2009)

Endangered Species		Threatened Species	
Mussels		Mussels	
Cumberlandia monodonta	Spectaclecase	*Alasmidonta viridis*	Slippershell
*Cyprogenia stegaria***	Fanshell	*Cyclonaias tuberculata*	Purple Wartyback
Epioblasma triquetra	Snuffbox	*Ellipsaria lineolata*	Butterfly
*Lampsilis abrupta***	Pink Mucket	*Elliptio crassidens*	Elephant-ear
Lampsilis fasciola	Wavy-rayed Lampmussel	*Elliptio dilatata*	Spike
*Lampsilis higginsii***	Higgins Eye	*Fusconaia ebena*	Ebonyshell
*Plethobasus cooperianus***	Orangefoot Pimpleback	*Ligumia recta*	Black Sandshell
Plethobasus cyphyus	Sheepnose	*Villosa lienosa*	Little Spectaclecase
*Pleurobema clava***	Clubshell		
Pleurobema cordatum	Ohio Pigtoe		
*Potamilus capax***	Fat Pocketbook		
Ptychobranchus fasciolaris	Kidneyshell		
Quadrula cylindrica	Rabbitsfoot		
Simpsonaias ambigua	Salamander Mussel		
Toxolasma lividus	Purple Lilliput		
Villosa iris	Rainbow		
Stoneflies			
Diploperla robusta	Robust Springfly		
Prostoia completa	Central Forestfly		

** = Federally Endangered
* = Federally Threatened

> *relatively few endemic species compared to other more stable regions, such as the Tennessee Uplands and the Ozark Plateau. Endemic species are those that are confined to a certain region or area. In general, areas with stable geologic and climatic history will have more endemic species than unstable regions. For example, the Great Lakes area, which also was covered by glaciers during the Pleistocene, has nine endemic fish species, whereas the climatically more stable Tennessee Uplands area has about 50 endemic fish species (Gilbert, 1980).*

Estimating Stressor Level from Species TIVs

A major reason for generating a BCG for the Dupage River and Salt Creek watersheds is to enhance restoration options and provide some predictable relationships between biological conditions, biodiversity and stressor levels in these watersheds. The multivariate and correlative measures we are undertaking using IBI and MBI measures to identify limiting stressors is one way to understand stressor impacts; this is a “top-down” approach. An alternative approach is to use information about individual species responses to stressors gained from broad scale studies of species sensitivities to infer 1) which stressors are limiting, 2) understanding the limiting nature of stressors, and 3) predict species occurrence and distribution under various stressor reduction scenarios; a “bottom-up” approach.

In this bottom-up, broad scale approach we generated Weighted Stressor Values (WSVs) and Tolerance Indicator Values (TIVs) for each species in our Midwest fish assemblage database (ECOS) for wadeable sites. Weighted stressor values are generated for every site where we have a species present and a stressor value, summing over all sites the product of the stressor values (typically means) and relative abundance estimates, and then dividing by the relative abundance summed over all sites. These weighted stressor values and other statistics are listed in Appendix 1 for each species and stressor in the Dupage River and Salt Creek historical and current dataset, including some species found in adjacent watersheds that might be expected to occur in the Dupage system. Each species is then ranked by these weighted stressor values and assigned an ordinal score (TIV) based on their rank with 1 being the most sensitive and 10 the most tolerant. TIV values based on the weighted stressor values are summarized in Appendix 2. We calculated TIVs for individual stressors and mean TIVs for categories of stressors including habitat, nutrients, organic enrichment, metals and ionic strength parameters.

Estimating Environmental Conditions at Sites based on Biological Assemblages

A key use of the weighted stressor values and TIVs was to use the biological assemblage data to estimate or infer what the stressor or environmental conditions are like at a site where we did not have complete stressor data or for historical and simulated sites where no stressor data exists. In the past we have done this by simply using the biological assemblage data at a site and calculating mean TIV values by creating a mean across all species weighted by the abundance of that species. For this analysis we are modifying this approach by adjusting the weight that a species gets on the stressor value by the presence of more sensitive species. Species presence/absence distribution curves can be of several forms. The “typical” hypothetical probability of occurrence curve in a “niche” sense is a unimodal curve illustrated in figure 3 from U.S. EPA (2006) for temperature. With stressor parameters, however, species

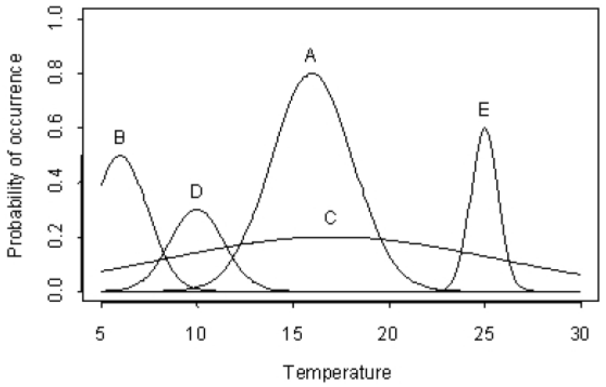


Figure 5. Hypothetic probability of different species in response to stream temperature (From U.S. EPA 2006).

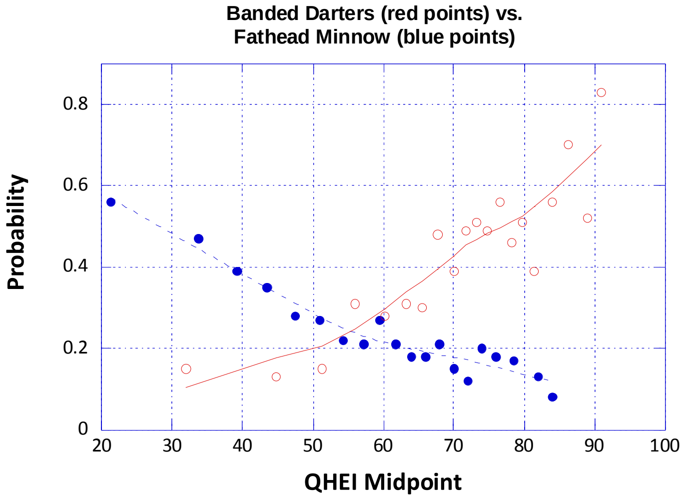


Figure 4. Probability of occurrence of banded darters (open circles) and fathead minnows (solid diamonds) in response to QHEI habitat score. Each data point for a species represents a bin of equal sample size along x-axis .

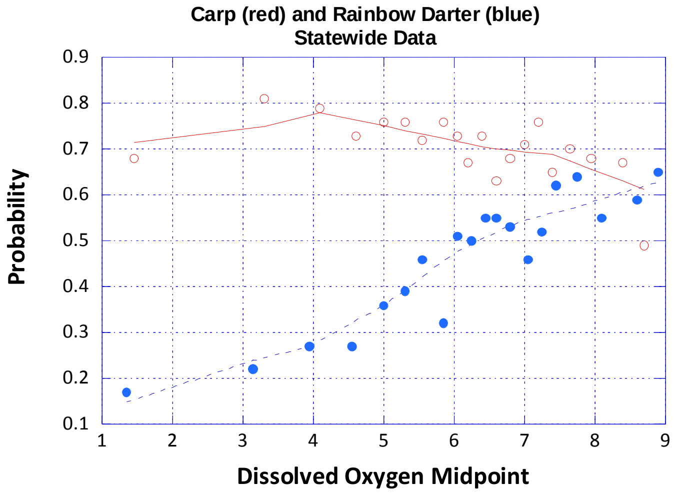


Figure 3. Probability of occurrence of common carp (open circles) and rainbow darter (solid diamonds) in response to minimum summer grab dissolved oxygen values (mg/l). Each data point for a species represents a bin of equal sample size along x-axis .

may be more likely increase or decrease monotonically with a stressor or show little response. Figure 4 illustrates or plots of the probability of occurrence of a species tolerant of habitat degradation (fathead minnow) which monotonically declines with increasing habitat quality and a habitat specialist (banded darter) which monotonically increases with increasing habitat quality.

Figure 5 illustrates a monotonically increasing response to dissolved oxygen for rainbow darter and a relative lack of response to DO for common carp. The dominance of carp in a catch may suggest low DO, especially if DO sensitive species are absent. The presence of carp when DO sensitive species are abundant suggests that DO is not limiting. Thus when using species to infer stressor levels we will take advantage of such conditional probabilities when estimating stressor levels. Rather than simply summing weighted stressor values for each species, weighted by abundance, we will use the response of a strongly sensitive or tolerant species to adjust the weight or influence of carp WSVs on an inferred stressor value. Plentiful rainbow darters, even in the presence of carp indicate high minimum DO values. This correction should help deal with the problem with inferences or calculations of stressor gradients using weight values become compressed.

Synthetic Fish Assemblage

As mentioned above we derived to “synthetic” fish assemblage for the Dupage River and Salt Creek watersheds using a computer program written to “fish” a hypothetical assemblage of fish species as might have existed prior to European settlement. Any attempt to ‘derive” such an assemblage is fraught with uncertainties, but we applied knowledge of how fish species respond today along a biological condition gradient based on actual ambient data, supplemented with hypothetic species population for species that are now rare, extirpated or extinct. For example, the Iowa darter, once collected in the Dupage River, and now rare in statewide collections, in streams has been associated with vegetated margins and presence of adjacent wetland and ponds. It is not generally found in vegetated ditches, but rather the margins of high quality streams with wetland features found in streams with generally very high QHEI scores and IBI scores. Our supposition, supported by historical notes and distribution data in other states where the Iowa darter populations are still strong is that the probability of capture was much higher when stream size wetlands and wet areas were still intact prior to settlement and agricultural drainage activities. Because of resource and time limitations we constructed synthetic communities based on some simple assumptions about their abundance changes at sites and could refine this approach in the future to more accurately adjust expectations with stream size.

Existing Data

We used data from Illinois, Indiana, Ohio and other neighboring Midwest states (e.g., Gerking 1945, Trautman 1981, Smith 1979) to derive estimates of capture probabilities for species along a gradient of biological condition as measured by the Ohio IBI. Capture probabilities were plotted by IBI ranges (12-19, 20-29, 30-39, 40-49, 50-60) separately for small headwaters (0.1 - 10 sq mi) and "large" headwaters (>10-20 sq mi) and three categories of wadeable sites (>20 – 50 sq mi, 50 -100 sq mi and 100-300 sq mi) to represent changes in capture probability that differ with changes in stream size as well as stream quality. Examples curves for select minnow species for headwater and wadeable streams are illustrated in Figure 6 for headwater (top) and wadeable (bottom) streams. This probability of capture for each IBI range for each species was stored in a data table. We examined each of these plots for species where data was sufficient and then extrapolated these probabilities to a pre-settlement (~BCG Tier 1) and a civil war era post-settlement time period (~BCG Tier 2). This was done with best professional judgment (BPJ) by examining these plots and using data from historical descriptions and life history attributes. For rare, extirpated, or extinct species we used what we could glean from early descriptions of these species (Smith 1979, Trautman 1981) to assign likely capture probabilities.

Once we had capture probabilities for each species for these extrapolated time periods to create a pool of over 100,000 fish based on the relative probability of capture rates we assigned by stream size category. We then "fished" these populations with a computer program that randomly selected species based on the capture probabilities and some constraints on the total species and total numbers captured that could be collected from a site. These constraints were based on examining existing high quality sites with IBI scores > 50. The fish assemblages from this output were then used to generate historical IBI

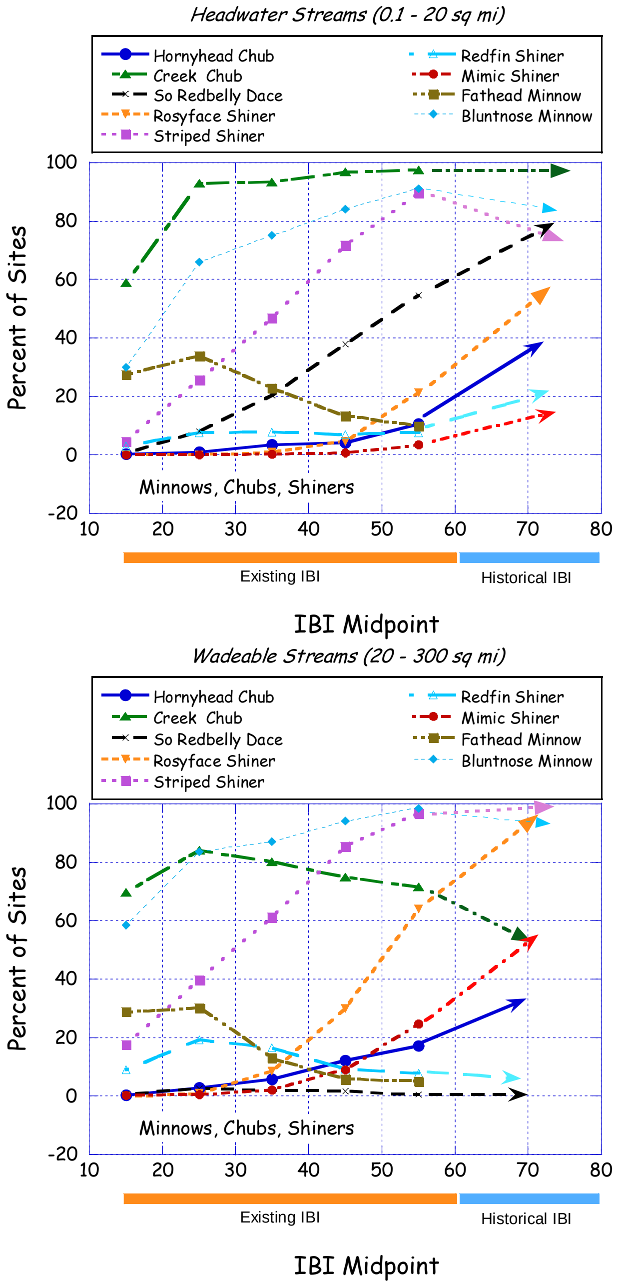


Figure 6. *Plot or probability of capture for selected minnow, chub, and shiner species vs. Ohio IBI range and showing extrapolation based on trends and BPJ to pre- and post-settlement time periods in Illinois (~1800 and 1860s).*

scores based on scoring criteria modified from the Ohio and Illinois IBIs and the species and abundances in these collections were used to estimate environmental conditions at these sites based on TIVs generated for each species. We also created some synthetic “current” assemblages to verify that the process was producing reasonable results; these test sites resulted in IBIs similar to expected based on the range of sampling probabilities we chose.

Results

BCG Components for the Dupage River and Salt Creek Watersheds

Table 4 contains the list of all fish species from the Dupage River and Salt Creek watersheds in Illinois and denotes inclusion in one or more of the BCG attributes (last column). In the next sections we propose straw-man species choices for each of the BCG attributes for the fish assemblages and for several BCG attributes using macroinvertebrates. We consider these as straw-man choices because these are more properly done by convening one or more workshops that bring together experts in these disciplines that may have insight into certain species because of research interest, field experience, studies performed, etc. For each attribute we identify two groups of species. The first are regular wadeable or headwater streams species and would be the primary core of the assemblages in the wadeable sections of the Dupage River and Salt Creek. The second group is termed: “occasional species” that would inhabit larger streams and rivers, but could routinely turn up in collections, especially in the lower reaches of these streams, if conditions were better.

Attribute 1. Historically documented, sensitive, long-lived, or regionally endemic taxa

As pointed out by the USGS report, the recolonization of the upper Illinois River system after glaciations did not allow for the development of extensive regional endemic taxa as in some other areas of the United States. The Dupage and Salt Creek watersheds are more difficult to assess in relation to this metric because some of the more sensitive species that could occur in these watersheds may have been reduced in population or extirpated before extensive collections were made. The wadeable and headwater streams that comprise the major of miles in these watersheds would likely have fewer of the very large, long-lived species expected in larger rivers. Most of the species we selected for this metric would have been associated with wetland and vegetated habitats with clear pools and clean stream bottoms. Smith (1979) report historical collections of Blacknose shiner from both the Dupage River system and Salt Creek; pugnose minnow was not collected from these systems, but from adjacent or nearby connected watersheds.

Many of these species are sensitive to pollutants and habitat loss in particular. Several species, such as American eel are more tolerant of pollutants, but were selected because of their importance in reflecting ecological connectance. Because of their great migration distance an abundance of this species would reflect that the Dupage River and Salt Creek were well connected downstream into the Gulf of Mexico. Again, the exercise of assigning such tiers is best done with teams of experts who can bring insight into the life history characteristics of these species and their assignment to various metrics; we consider these attributes as draft and subject to input by regional experts in Illinois and the Midwest.

Table 7. Candidate fish species for attribute 1 of the BCG, Historically documented, sensitive, long-lived, or regionally endemic taxa. Some of these occurred in neighboring watersheds and their definite occurrence in the Dupage or Salt Cr watersheds is uncertain.

Common Name	*Latin Name*	Illinois ETS Status
Regularly Occurring Headwater and Wadeable Stream Species		
Blacknose Shiner	*Notropis heterolepis*	E
Pugnose minnow	*Notropis emiliae*	
Iowa Darter	*Etheostoma exile (Girard)*	T
Greater redhorse	*Moxostoma valenciennesi*	E
Starhead topminnow	*Fundulus dispar*	T
Occasional Species from Mainstem		
American eel	*Anguilla rostrata* (Lesueur)	

Attribute 2. Rare, Sensitive Taxa

The rare, sensitive attribute reflects a general sensitivity to stressors influencing small Midwest streams such as the Dupage River and Salt Creek (Table 8). In the Midwest, there are few rare headwater fish species, since these streams are "naturally" somewhat harsh and variable compared to larger streams. Most of these species are still extant in Dupage River or adjacent watersheds, but could be more common in catches if streams were closer to natural conditions with regard to stressors. This group especially reflects sensitivity to the habitat loss and sedimentation.

Table 8. Candidate fish species for attribute 2 of the BCG, Rare, sensitive taxa. These species are still generally extant in the nearby mainstem reaches or in adjacent watersheds. Codes: X – Extirpated, XT – Extinct, E – Endangered, T – Threatened, S – Special Concern.

Common Name	*Latin Name*	Illinois ETS Status
Regularly Occurring Headwater and Wadeable Stream Species		
black redhorse	*Moxostoma duquesnei*	
rosyface shiner	*Notropis rubellus*	
creek chubsucker	*Erimyzon oblongus*	
slender madtom	*Noturus exilis*	
Occasional Species from Mainstem		
river redhorse	Moxostoma carinatum	T
mimic shiner	Notropis volucellus	
pallid shiner	Notropis amnis	E
yellow bass	Morone mississippiensis	
slenderhead darter	Percina phoxocephala	

Attribute 3. Sensitive, Ubiquitous Taxa

The sensitive and ubiquitous taxa represent those species considered sensitive, and are generally numerically predominate in natural communities (Table 9). Although they may not be as sensitive as the rare and endemic taxa and may be able to persist though increased stressor levels, they are generally at highest abundance where stressors are lowest. Because they can persist at low numbers with some stress and increase numerically with reductions in stressor, they provide much useful information related to the existing conditions of the Dupage River and Salt Creek watersheds.

Table 9. Candidate fish species for attribute 3 of the BCG, Sensitive, ubiquitous taxa. These species should be relatively common and currently have been recently collected in the Dupage River, Salt Creek or adjacent watersheds. Codes: X – Extirpated, XT – Extinct, E – Endangered, T – Threatened, S – Special Concern.

Common Name	*Latin Name*	Illinois ETS Status
Regular Wadeable Species		
hornyhead chub	*Nocomis biguttatus*	
southern redbelly dace	*Phoxinus erythrogaster*	
striped shiner	*Luxilus chrysocephalus*	
sand shiner	*Notropis stramineus*	
largescale stoneroller	*Campostoma oligolepis*	
smallmouth bass	*Micropterus dolomieui*	
golden redhorse	*Moxostoma erythrurum*	
shorthead redhorse	*Moxostoma macrolepidotum*	
northern hog sucker	*Hypentelium nigricans*	
stonecat madtom	*Noturus flavus*	
rock bass	*Ambloplites rupestris*	
warmouth sunfish	*Lepomis gulosus*	
longear sunfish	*Lepomis megalotis*	
blackside darter	*Percina maculata*	
logperch	*Percina caprodes*	
banded darter	*Etheostoma zonale*	
Least darter	*Etheostoma microperca*	
Occasional Mainstem Species		
northern pike	*Esox lucius*	
silver redhorse	*Moxostoma anisurum*	
shorthead redhorse	*Moxostoma macrolepidotum*	
bullhead minnow	*Pimephales vigilax*	
flathead catfish	*Pylodictis olivaris*	
spotted sucker	*Minytrema melanops*	

Attribute 4. Species of Intermediate Tolerance. These are fish species that are not especially sensitive to most stressors and will be predominant if stressors reduce populations of species in attributes 1-3 and reduce competition and/or predation on intermediate tolerance species (Table 10). These species may be predominant in tier 4 streams and still important members of the assemblage in tier 5 streams, although typically reduced in abundance.

Table 10. Candidate fish species for attribute 4 of the BCG, taxa of intermediate tolerance. These species are relatively common and may increase in abundance in the Dupage River system with increasing stressors and loss of more sensitive taxa.

Common Name	*Latin Name*
Spotted sucker	*Minitrema melanops*
suckermouth minnow	*Phenacobius mirabilis*
spotfin shiner	*Cyprinella spiloptera*
redfin shiner	*Lythrurus umbratilis*
Common shiner	*Luxilus cornutus*
central stoneroller	*Campostoma anomalum*
longnose gar	*Lepisosteus osseus*
bowfin	*Amia calva*
gizzard shad	*Dorosoma cepedianum*
quillback carpsucker	*Carpiodes cyprinus*
emerald shiner	*Notropis atherinoides*
Tadpole madtom	*Noturus gyrinus*
channel catfish	*Ictalurus punctatus*
white crappie	*Pomoxis annularis*
black crappie	*Pomoxis nigromaculatus*
largemouth bass	*Micropterus salmoides*
yellow perch	*Perca flavescens*
freshwater drum	*Aplodinotus grunniens*
brown bullhead	*Ameiurus nebulosus*
black bullhead	*Ameiurus melas*
blackstripe topminnow	*Fundulus notatus*
western mosquitofish	*Gambusia affinis*
Brook silverside	*Labidesthes sicculus*
orangespotted sunfish	*Lepomis humilis*
Pumpkinseed sunfish	*Lepomis gibbosus*
johnny darter	*Etheostoma nigrum*
Fantail darter	*Etheostoma flabellare*
Orangethroad darter	*Etheostoma spectabile*
river carpsucker	*Carpiodes carpio carpio*
spottail shiner	*Notropis hudsonius*
ghost shiner	*Notropis buchanani*
white bass	*Morone chrysops*

Attribute 5. Tolerant Species.

These are fish species that are especially tolerant to most stressors and will be predominant at high stressor levels (Table 11). At the very highest stressor levels, however, even most of these will be reduced. In certain headwater streams, particularly those affected strongly by wetlands certain species (central mudminnow, golden shiner) are indicators of the natural harshness of the system, not human induces stressors.

Table 11. Candidate fish species for attribute 5 of the BCG, tolerant taxa. These species are relatively common and may increase in abundance in the Wabash River system with increasing stressors and loss of more sensitive taxa.

Common Name	*Latin Name*
bluntnose minnow	*Pimephales notatus*
fathead minnow	*Pimephales promelas* Rafinesque
bluegill sunfish	*Lepomis macrochirus*
white sucker	*Catostomus commersoni*
creek chub	*Semotilus atromaculatus*
yellow bullhead	*Ameiurus natalis*
green sunfish	*Lepomis cyanellus*
golden shiner	*Notemigonus crysoleucas*
central mudminnow	*Umbra limi*

Attribute VI: Nonnative or intentionally introduced taxa. These are fish species that are have either been introduced or have escaped and are now resident in Illinois. Some (e.g., silver and bighead carp) are more deleterious than others (Table 12), but are not expected to be dominant in the Dupage River and Salt Creek because they more commonly inhabit larger waterbodies. Many of these are moderately to highly tolerant.

Table 12. Candidate fish species for attribute 6 of the BCG, alien species. These species have been found and have resident populations or are stocked in the Wabash River system.

Common Name	*Latin Name*
Regularly Occurring Headwater and Wadeable Stream Species	
common carp	*Cyprinus carpio*
goldfish	*Carassius auratus*
common carp x goldfish	*HYBRID*
Occasional Species from Mainstem	
grass carp	*Ctenopharyngodon idella*
silver carp	*Hypophthalmichthys molitrix*
bighead carp	*Hypophthalmichthys nobilis*
striped bass	*Morone saxatalis*

Attribute VII. Changes in organism condition or increase in anomalies in response to pollution gradients. We propose several commonly used biological metrics to gauge the condition of this attribute. Ohio and other states have successful used fish anomalies to measure exposure to toxic conditions and severe pollution (Table 13).

Table 13. Candidate measures of organism condition for fishes in the Wabash River system.

Name	Description
Anomalies	*Rate of disease, deformities, eroded fins and tumors noted on fish species during data collection*
Multiple Year Classes	*Populations of all expected year classes should exist for all species in Attribute groups 1-3*
High diversity based on numbers and weight	*MIwb and subcomponents based on numbers and weight*

Attribute VIII. Disruptions of function at the ecosystem level. Natural systems have very complex ecosystem functions that result in high diversity and abundance of various trophic guilds. We will use these structure measures to infer healthy ecosystem function (Table 14).

Table 14. Candidate measures of to infer ecosystem functioning is intact for fishes in the Wabash River system.

Name	Description
Invertivores	*The Dupage River and Salt Creek were characterized by large numbers of site feeding insectivores that fed on the high diversity and production of aquatic invertebrates in the clear prairie streams that dominated after the last glaciation*
Top Carnivores	*The lower reaches of the Dupage River and Salt Creek supported a high diversity and production of top carnivores that fed on abundant forage fish and other organisms supported by energy movement through this system.*
Omnivores	*Omnivores were likely not predominant in the Dupage River and Salt Creek given the abundant insects and mussel assemblages that occurred in the river*

Attribute IX. Influence of spatial and temporal scale of disturbance on biological response and recovery potential. This is an especially important attribute for Midwest streams. Data from Indiana (see Figure 7) and Ohio has identified that widespread habitat loss is associated with intensive agricultural drainage and stream alteration which in turn limits fish assemblage condition. This has resulted in extirpation of sensitive species of fish, mussels, and invertebrates from watersheds. The stressors associated with these extreme habitat alterations include increase nutrients and sediments, greatly altered stream hydrology (increases in flashiness and drought) and loss of biological diversity to downstream reaches via species loss. At the Huc11 watershed scale we have documented the decline of sensitive species with the scale of habitat damage in these watersheds (Figure 7).

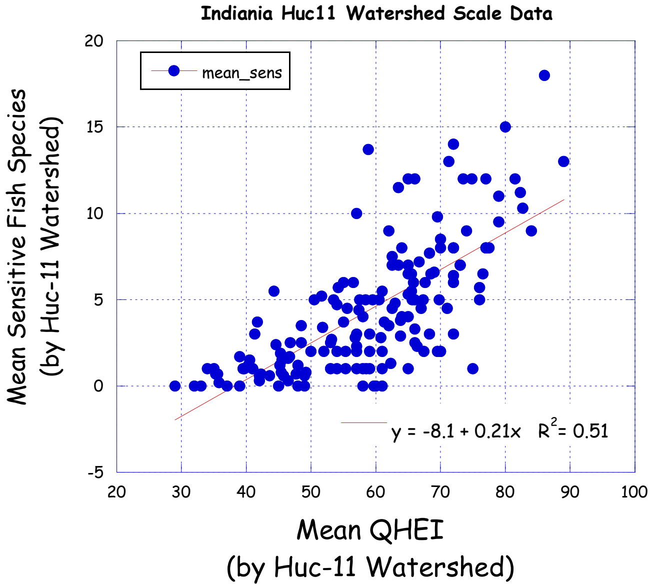


Figure 7. Plot of mean QHEI in Huc-11 watersheds with mean IBI scores in these watersheds for sites collected in Indiana by IDEM from 2001-2006.

Attribute X. Ecosystems connectance. This is related somewhat to the previous metric, but focuses on more directly blocks (e.g., dams) or other impediments to movements of taxa or species. Dams are plentiful in the Dupage River and have been shown to have an impact on Dupage River fish assemblages. Segments of highly polluted water can also impede connectance. Other serious affects on connectance occur downstream (Illinois River locks/dams) and in the loss of connectance with floodplain wetlands, sloughs and oxbows that were once characteristic of most Midwest prairie rivers and streams. Many of the intolerant species that are rare or extirpated were associated with these connected, but off-river habitats.

Modifying the IBI to Apply to Historical Conditions

The Index of Biotic Integrity is typical calibrated using the best existing conditions that related to either minimally impacted reference sites, least impacted reference sites or best attainable given current landscape conditions. The Fish IBI for Illinois and the current biocriteria-based IBI for fish in Ohio were created in this manner. These IBIs are not designed to be sensitive to Tier 1 or 2 historical data because the upper bounds of species richness metrics were generated using existing data which is less rich than historical populations. Thus an IBI calculated with historic data with maximal species richness values would be scored similarly to the best available reference sites. This is not an issue for scoring data collected from current stations; however it is not appropriate for the historical "synthetic" data we generated with our computer model.

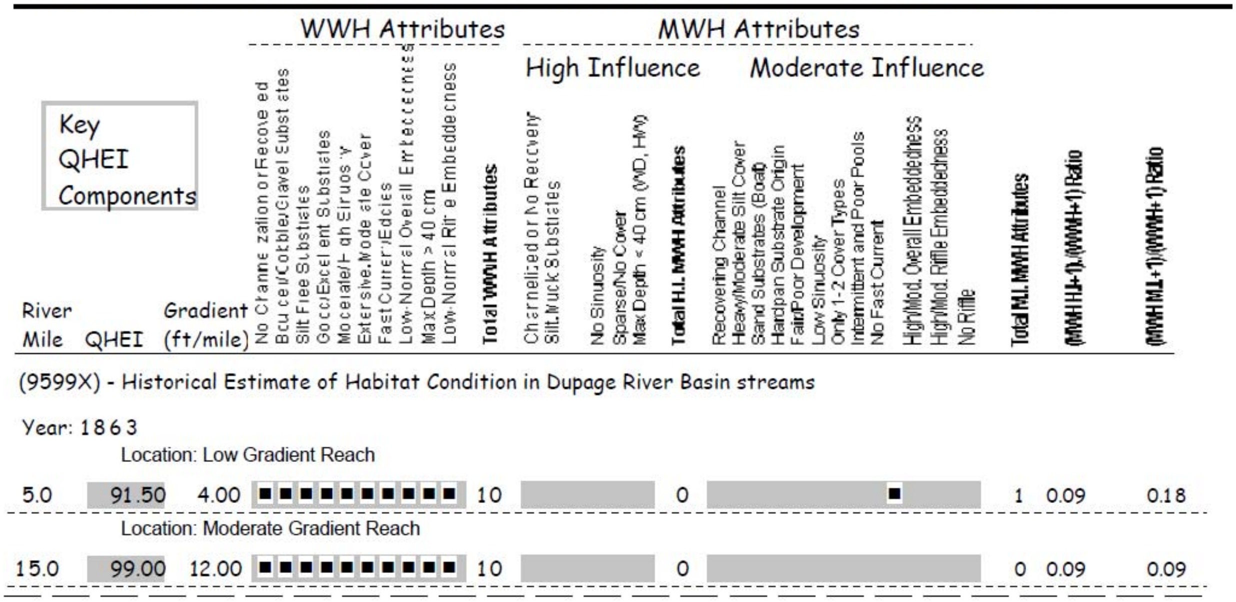
Ohio EPA recently has begun to test a newer, continuous scoring fish IBI that is not limited to three discrete metric scores (i.e., 1-3-5), but rather it scores each metric as a continuous variable with any possible score between 0 and 10. In addition, this effort recognized that current condition represents assemblages that may have lost some number of sensitive species, thus it was designed to extend scoring at the upper range of each metric to capture potential improvements to stream condition over time or allow scoring of "synthetic" assemblages that approximate Tier 1 and 2 streams as we developed for this study. Because of this we ran the fish assemblages through this proposed continuous "BCG" based IBI to see whether modeled synthetic assemblages would score substantially higher than existing best conditions. The disadvantage of this approach is that the IBI is not calibrated to Northeast Illinois assemblages and particularly to low gradient reaches. It is more appropriate for moderate gradient reaches of the Dupage watershed, but should still provide some insight into how current fish assemblages relate to historical conditions related to fish assemblage condition.

Human Disturbance Gradients

We generated historical (Tier 1-2) QHEI scores based on early settler's descriptions of the physical appearance of the Dupage River and tributaries, data from the best sites left in the Dupage River, and data from nearby reference sites just outside of the Dupage River watershed. We reconstructed a site from a lower gradient wetland dominated reach that was predominant in the watershed and from a moderate gradient reach that was likely common in other areas of the watershed (Table 15).

The highly stable vegetated prairies, wetlands and forested likely resulted in low erosion rates and the streams reaches were likely relatively free of silts. The higher gradient reaches were more likely to have generally larger substrates (gravels, cobbles, some boulders) compared to lower gradient reaches that were likely characterized by more gravel sand substrates although they were both likely to have low silt loads. There was likely wide diversity of substrate habitats available ranging from coarse materials in the flowing habitats, clean sandy bars in many depositional, but flow influenced reaches and stable detrital and organic muck habitats in wetland areas that characterized the oxbows, sloughs, sidewaters and backwater areas. In-stream structure was likely high and stable in both types of streams. The stable vegetation in these watersheds likely promoted good base flows even during most low flow periods. Aquatic plants were likely predominant in shallow water areas, particularly where prairies allowed sufficient light to reach the streams and or where the streams were wide. In comparison to today the streams were much less hydrological flashy because of the prairie and wetland vegetation. Riparian vegetation was much more mature and extensive than it is today.

Table 15. Reconstructed historical estimation of habitat conditions at two wadeable stream stations (one low gradient and one moderate gradient) in the Dupage/Salt Creek watersheds. The reconstruction of this QHEI is provided as an "anchor" for interpreting habitat conditions. Feasible goals for habitat rehabilitation would likely be somewhere between these values and existing values shown in later tables.



Key QHEI Components

(9599X) - Historical Estimate of Habitat Condition in Dupage River Basin streams

Year: 1863

			WWH Attributes											MWH Attributes																				
														High Influence						Moderate Influence														
River Mile	QHEI	Gradient (ft/mile)	No Channelization or Recovered	Boulder/Cobble/Gravel Substrates	Silt Free Substrates	Good/Excellent Substrates	Moderate/High Sinuosity	Extensive/Moderate Cover	Fast Current/Eddies	Low-Normal Overall Embeddedness	Max Depth > 40 cm	Low-Normal Riffle Embeddedness	**Total WWH Attributes**	Channelized or No Recovery	Silt/Muck Substrates	No Sinuosity	Sparse/No Cover	Max Depth < 40 cm (WD, HW)	**Total H.I. MWH Attributes**	Recovering Channel	Heavy/Moderate Silt Cover	Sand Substrates (Boat)	Hardpan Substrate Origin	Fair/Poor Development	Low Sinuosity	Only 1-2 Cover Types	Intermittent and Poor Pools	No Fast Current	High/Mod. Overall Embeddedness	High/Mod. Riffle Embeddedness	No Riffle	**Total M.I. MWH Attributes**	**(MWH H.I.+1)/(WWH+1) Ratio**	**(MWH M.I.+1)/(WWH+1) Ratio**
Location: Low Gradient Reach																																		
5.0	91.50	4.00	■	■	■	■	■	■	■	■	■	■	10						0									■				1	0.09	0.18
Location: Moderate Gradient Reach																																		
15.0	99.00	12.00	■	■	■	■	■	■	■	■	■	■	10						0													0	0.09	0.09

Initial Reconstruction of Environmental Conditions to Match BCG Tiers 1 and 2

The synthetic fish assemblages we created were designed to approximate Tiers 1 and 2 of the BCG described above. Although we do not have the resources to explore these patterns in depth, we generated "inferred" environmental conditions based on the overall TIV scores for the synthetic and existing data and plotted it versus the continuous "BCG-enabled" IBI that Ohio has developed (Figures 8 and 9). TIV scores for individual stressor categories are developed by arraying species along the stressor gradient and developing 10 ordinal groups based on where a species ranks for each stressor relative to all other species. Thus 10 percent of the species will have a rank of 1 for a stressor (most sensitive) and 10 percent will have a rank of 10 (most tolerant). We infer the stressor load at a site by creating a weighted rank of all species that are present with the weighting factor the abundance of each species. The synthetic data stand alone along the biological gradient as expected and along the inferred stressor gradients.

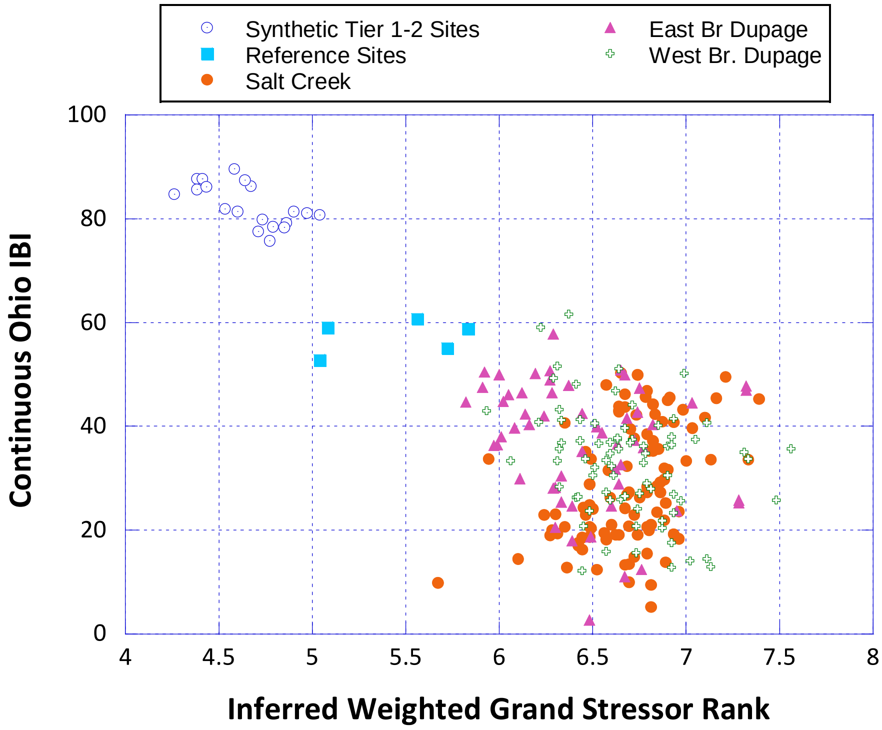


Figure 8. Plot of the inferred grand rank of all stressor categories generated for individual fish sampling sites in the Dupage and Salt Creek watersheds sampling between 2006 and 2009, some reference sites in nearby watersheds, and from a hypothetical, modeled fish assemblage for headwater and wadeable sites in the Dupage River watersheds that represent pre-settlement and immediate post-settlement (circa 1860s) conditions. Ranking based on TIV values by species for multiple stressor categories generated for Midwest streams.

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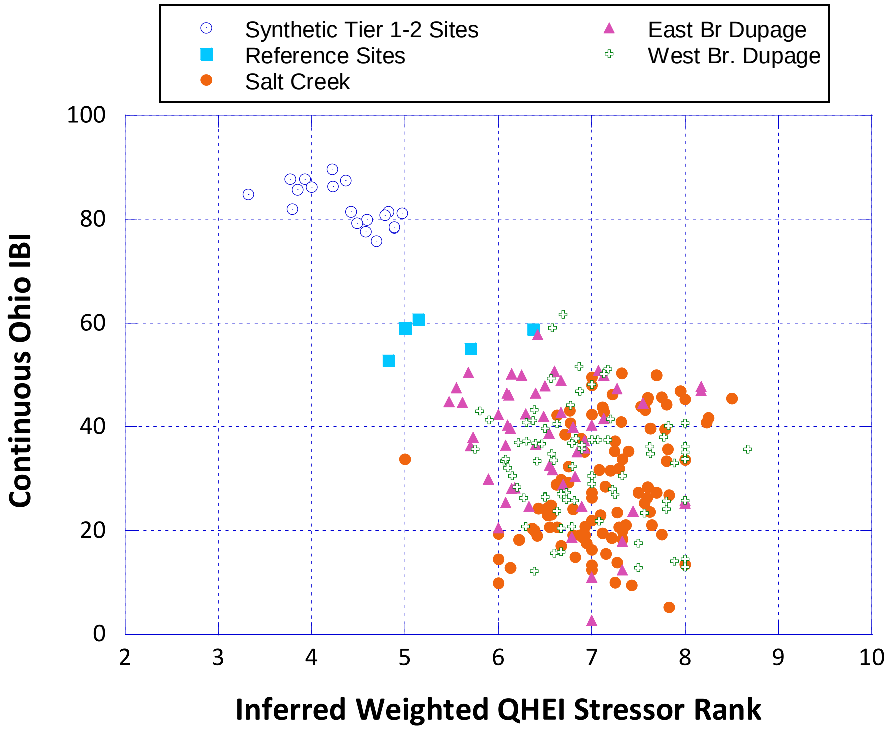

Figure 9. Plot of the inferred QHEI rank of generated for individual fish sampling sites in the Dupage and Salt Creek watersheds sampling between 2006 and 2009, some reference sites in nearby watersheds, and from a hypothetical, modeled fish assemblage for headwater and wadeable sites in the Dupage River watersheds that represent pre-settlement and immediate post-settlement (circa 1860s) conditions. Ranking based on TIV values by species for QHEIs generated for Midwest streams.

Conclusions

The Dupage River and Salt Creek watersheds have suffered from a long series of perturbations, minimally starting with pre-Columbian occupation by humans, but accelerating greatly with European settlement and with the intensive urban development in the Eastern portion of the watersheds represent some of the most severe land use changes that can be expected. Some of the species that existing before settlement have been extirpated (e.g.,) and many other have declined in abundance and distribution, but some have rebounded in the past 20 years from the worst of the waste water impacts that were associated with untreated or partially treated effluents.

The construction of a BCG for the Dupage River and Salt Creek watersheds provides a historical "endpoint" but not an attainable goal for watershed with that level of population and urbanization. Such an endpoint, however, provides a useful "point" in a trajectory between historical and existing conditions for consideration of reasonable rehabilitation measures. We feel this is an initial, cursory assessment of such data, but sets a baseline for determining what might be feasibly restorable. It approaches the question of how stressors are likely limiting streams in these watersheds from a more narrative, historical perspective than the statistical approach used in the body of the report. The various species lists compile as part of the BCG effort (e.g., attribute 3, sensitive species) can provide candidate species to track as indicators of progress with restoration efforts.

We suggest that, in addition to biological indices as the best overall measure of recovery, a group of attribute 3 species could serve as useful indicators of success and a useful communication tool (Table 16).

Table 16. Candidate recovery indicator fish species (from the "sensitive, ubiquitous" attribute of the BCG). With recovery these species should increase their distribution and relative abundance.

Common Name	*Latin Name*	Illinois ETS Status
Regular Wadeable Species		
hornyhead chub	*Nocomis biguttatus*	
southern redbelly dace	*Phoxinus erythrogaster*	
striped shiner	*Luxilus chrysocephalus*	
sand shiner	*Notropis stramineus*	
largescale stoneroller	*Campostoma oligolepis*	
smallmouth bass	*Micropterus dolomieui*	
golden redhorse	*Moxostoma erythrurum*	
shorthead redhorse	*Moxostoma macrolepidotum*	
northern hog sucker	*Hypentelium nigricans*	
stonecat madtom	*Noturus flavus*	
rock bass	*Ambloplites rupestris*	
warmouth sunfish	*Lepomis gulosus*	
longear sunfish	*Lepomis megalotis*	
blackside darter	*Percina maculata*	
logperch	*Percina caprodes*	
banded darter	*Etheostoma zonale*	
Least darter	*Etheostoma microperca*	

Conversely, tolerant indicator species (Table 17), may not decline in distribution, but should decline in abundance as they are "out-competed" by sensitive fish species.

Table 17. Candidate recovery indicator fish species that should decline as stressors lessen. These species will always be present, but should only be predominant under limited circumstances.

Common Name	*Latin Name*
bluntnose minnow	*Pimephales notatus*
fathead minnow	*Pimephales promelas* Rafinesque
bluegill sunfish	*Lepomis macrochirus*
white sucker	*Catostomus commersoni*
creek chub	*Semotilus atromaculatus*
yellow bullhead	*Ameiurus natalis*
green sunfish	*Lepomis cyanellus*
golden shiner	*Notemigonus crysoleucas*
central mudminnow	*Umbra limi*

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