Streams of Hope:

Characterizing the Biological Potential of Moderately Urbanized Connecticut Streams

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Cover photograph:

Connecticut Department of Environmental Protection file photo. Connecticut Department of Environmental Protection, Hartford, CT. East Branch Naugatuck River in Torrington, Connecticut has approximately 9.4% impervious cover in the watershed and this location was selected as one of the streams of hope study sites. Photo taken October 5, 2006.

Abstract

The negative effect of urbanization on the health of macroinvertebrates was examined for sampling locations in 26 streams in Connecticut that ranged from 6-14% total impervious land cover (IC) in the upstream drainage basin. We developed a conceptual model for stream classes and management strategies using IC as the stressor of interest. We then used the conceptual model to develop an expected range of macroinvertebrate multimetric index (MMI) scores using IC as the predictor variable. We found that 80% of the 26 sites sampled had MMI scores that were within the expected range as predicted using IC as a predictor variable. We also examined the longitudinal effect of urbanization on MMI scores at five locations by sampling upstream and downstream of clusters of urbanization. In all five examples tested, the MMI score showed a decline in stream health below urban clusters relative to sites upstream. We also grouped macroinvertebrate taxa into ecological attribute groups - highly sensitive, intermediate sensitive, intermediate tolerant, tolerant, and exotic/invasive taxa. Highly sensitive taxa were present in two of the longitudinal sites but in both cases absent in the downstream site below an urban cluster. Further, the density of intermediate sensitive taxa was higher at sites upstream of urban clusters compared to sites downstream of urban clusters in all five comparisons. Finally, we extend the general IC conceptual model further to propose the use of IC as a reasonable predictor of biological potential of streams in Connecticut.

KEY TERMS: invertebrates, environmental indicators, urbanization, impervious cover, streams, biological potential

Introduction

The negative effect of urbanization on the health of aquatic biota in rivers and streams has been well documented (Schuler, 1994; Morley and Karr, 2002; Coles *et al*., 2004) The phrase “urban stream syndrome” (Walsh *et al*., 2005) has been used to describe the consistent pattern of ecological degradation of streams draining urban lands. Impervious land cover (IC) has often been used as a surrogate measure of the aggregate negative effects of urbanization on hydrology (Arnold and Gibbons, 1996; Schuster *et al*., 2005; Galster et al., 2006; Olivera and Defee, 2007); geomorphology (Cianfrani *et al*., 2006); and biological communities (Wang *et al*., 2001; Morse *et al*., 2002; Wang and Kanehl, 2003; Miltner *et al*., 2004; Stanfield and Kilgour, 2006). Thus stressors such as impervious land cover can provide a useful gradient to assess biological communities and the health of aquatic ecosystems (Barbour *et al*., 2006).

The Connecticut Department of Environmental Protection (CTDEP) has modeled the multiple stressors associated with stormwater runoff from impervious surfaces and ecological degradation of macroinvertebrates within the context of the State’s Total Maximum Daily Load (TMDL) Program. To support this approach, the percent IC in the upstream drainage basin and scores of macroinvertebrate health were modeled for drainage basins less than 130 square kilometers in Connecticut. These data showed that once IC in the upstream drainage basin reached approximately 12%, none of the 125 sites analyzed met the state's aquatic life goals (Bellucci, 2007). The Connecticut IC TMDL model provided the scientific foundation for setting targets and implementation goals that relate IC to stormwater management and aquatic life in Connecticut streams and supported the generalized relationship between stream health and IC characterized by Schuler (1994).

We believe that the utility of IC as an important variable in water quality management in Connecticut extends beyond the regulatory framework of the TMDL Program. IC can provide a conceptual model that can be useful to group streams into classes and develop management strategies for Connecticut streams (Figure 1). This conceptual model describes the biological potential of streams relative to IC and provides a very useful communication tool to describe the potential impacts of land use decisions on stream health. Further, this conceptual model can be used to frame future research and management strategies in Connecticut. For example, a range of IC can be chosen *a priori* to test assumptions of expected biological condition. Sampling locations that fall within the expected condition (e.g. low numbers of sensitive macroinvertebrate taxa at 20% IC in the upstream drainage basin) would be consistent with this conceptual model. Sampling locations that do not conform to the model (e.g. low numbers of sensitive macroinvertebrate taxa at 2% IC in the upstream drainage basin) provide good candidate sites for future investigative work that would focus on identifying the reasons for deviation from the model.

In this study, we focused on streams that fall in the “streams of hope” and “active management” range of our conceptual model (Figure 1). Streams within this mid-IC range are termed “streams of hope” because previous work indicated that active management may be required for some of these streams to meet their biological potential (Bellucci, 2007). We believe that the important aspect of our conceptual model as it applies to “streams of hope” is that active management can improve stream biology (i.e. these are the streams to study since there is a greater likelihood that active management will effect biological change so streams meet their biological potential). We defined “streams of hope” as those drainage basins in Connecticut with 6-14% IC. The 6-14% IC range was chosen using 12% IC as a starting point since previous work has identified macroinvertebrate communities at sites in Connecticut with > 12% IC do not meet aquatic life goals in Connecticut (Bellucci, 2007), and then further expanding the 12% to a range recognizing the complexity and variability among stream systems along the continuum of disturbance and stream quality (e.g. Davies and Jackson, 2006).

We used Geographic Information Systems (GIS) to select study sites in Connecticut that were in the mid-range of watershed percent IC (6-14%) and therefore a presumed mid-range of stream quality. We collected macroinvertebrate samples and quantified relationships between IC and stream health as measured by macroinvertebrate metrics and a composite macroinvertebrate index scores from 26 streams in Connecticut. We determined, *a priori*, an expected range of composite macroinvertebrate index scores using IC as a selection filter to validate the study site predictions. In addition, we examined the longitudinal effects of the IC stressor gradient in five watersheds by selecting sampling locations above and below known urbanization clusters.

The objectives of this study were to: 1) evaluate whether sites chosen *a priori* within a mid-range of IC (6-14%) would have macroinvertebrate metric scores within an expected range of stream health; and 2) evaluate the effect of increasing amounts of impervious cover on macroinvertebrate metric scores within the same watershed. We then discuss the relationship of these data with a previous analysis of 125 streams from Connecticut (Bellucci, 2007) and make recommendations for future work.

Methods

The selection of sites for this study involved two steps. First, drainage basins (Langbein and Iseri, 1960) were initially screened using GIS to determine the total IC in the basin was within the target 6-14% IC range (“Initial Screening of Drainage Basins” below). Second, drainage basins meeting the 6-14% IC criterion were field checked to determine the most suitable sampling location and unsuitable sites were eliminated. Drainage basins upstream of suitable sampling sites were delineated and the percent IC of the study drainage basin was calculated using GIS (“Selection of Study Sites and Delineating the Drainage Basins” below).

Initial Screening of Drainage Basins

Thomas (1972) divided Connecticut into natural drainage basins and we targeted small to medium sized basins termed ‘subregional basins’. Connecticut contains 334 subregional basins that range in size from 0.21 – 457.03 square kilometers, although 95% are less than 101.01 square kilometers (median = 27.07 square km). Subregional basins in Connecticut that ranged from 6-14% IC were screened as potential sites for this study. We calculated the percent IC of potential study basins using the Impervious Surface Analysis Tool (ISAT) (NOAA, 2007). ISAT is an extension used in conjunction with GIS software, ESRI Arc Map version 9.1, which was developed by the Coastal Services Center at the National Oceanic and Atmospheric Administration in collaboration with the Non Point Education for Municipal Officials (NEMO) program at the University of Connecticut. GIS analyses in this study were completed with ESRI ArcMap 9.1, and will be referred to as GIS hereafter. ISAT uses an inference method to calculate total IC for a defined polygon based on land cover coefficients and human population density. In this study the polygon was defined as the drainage basin upstream of the study site and we used land cover coefficients developed for Connecticut based on 2002 Connecticut Land Cover data and Census 2000 population density (Prisloe et al. 2002). The 2002 Connecticut Land Cover data were derived from satellite images at a 30 meter pixel resolution (CLEAR, 2008). A high population density was defined as > 1800 people/square mile, medium was 500 – 1800 people/square mile, and low was <500 people/square mile.

After using ISAT to identify subregional basins with 6-14% IC, those that contained sewage treatment plants and those basins that extended beyond the Connecticut border were eliminated as study basins. We then field checked the remaining subregional basins and eliminated those with unsuitable habitat for macroinvertebrate sampling (e.g. low gradient sites with no riffle), brackish or salt water (e.g. small coastal basins), or non-wadable conditions (e.g. main-stem of large rivers such as the Connecticut River).

Selection of Study Sites and Delineating the Drainage Basins

After initial screening of subregional basins with ISAT and subsequent field checking, a total of 32 sites were selected for this study (Figure 2). These sites were categorized into three types – mid IC sites (n=26), longitudinal sites (n=5), and a benchmark site (n=1).

A total of 26 mid-IC sites had suitable riffle habitat, adequate site access, and were wadeable. At five of these sites- Hancock Brook, Muddy River, Steele Brook, East Branch Naugatuck River and West Branch Naugatuck River- we selected a second sampling site upstream of urbanization clusters to provide a comparison of the macroinvertebrate community against a gradient of IC on the same stream (longitudinal sites). We also evaluated one site in the Saugatuck River located within close proximity to the study sites to provide a relative measure of environmental conditions for the sampling year (benchmark site). Sampling locations for each of the mid IC and longitudinal sites were chosen by beginning at the drainage basin pour point and field inspecting accessible streams for suitable riffle habitat. In general, the first location encountered with suitable access and habitat within close proximity to the drainage basin pour point was selected as the sampling location for each study site. The latitude and longitude of each study site was recorded with a Garmin Model 76 Global Position System to delineate the drainage basin for each study site and to calculate drainage basin characteristics using GIS. The drainage basin of each study sites was delineated using the ArcHydro extension of GIS. The percent impervious cover upstream of the selected study sites was then calculated for each drainage basins using ISAT.

Macroinvertebrate Community

Benthic macroinvertebrates were collected from all 32 sites during September - October, 2006 using an 800 *u*m-mesh kick net and sampling 2 m^2 of riffle habitat at each location. Benthic samples were preserved in 70% ethyl alcohol and brought back to the laboratory for sub-sampling. A 200-organism sub-sample using a random grid design (Plafkin *et al*., 1989) was used to calculate metrics and a macroinvertebrate multi-metric index (MMI) score for each sampling location. MMI scores for each site were calculated at the genus level. The MMI is the arithmetic average of 7 metrics - Ephemeroptera taxa (scoring adjusted for watershed size), Plecoptera taxa, Trichoptera taxa, percent sensitive EPT (scoring adjusted for watershed size), scraper taxa, biological condition gradient taxa biotic index, and percent dominant genus (Gerritsen and Jessup, 2007). The MMI values are unit-less scores that range from 0 - 100 with higher values representing least stressed sites.

Data Analyses

Macroinvertebrates

A benchmark site on the Saugatuck River was selected to compare the MMI score and seven macroinvertebrate metrics from the year of this study (2006) to the previous nine years using a dot plot. The Saugatuck River site was chosen as the benchmark site because 1) of its 10 year data set of benthic macroinvertebrate samples collected using methodologies consistent with this study and 2) its location in the same geographic area as the group of test study sites (Figure 2) and 3) there is a record of average daily discharge at this locations from 1967-2007 (USGS gage 01208990 Saugatuck River near Redding, CT).

The 26 mid IC sites were evaluated by comparing MMI scores to an expected range of MMI scores chosen *a priori*. The expected MMI range for the 26 mid IC sites was based on previous work on the Connecticut IC Model (Bellucci, 2007). We identified all sites from the Connecticut IC Model that were within the targeted percent IC range from this study (i.e. 6-14%) and calculated the interquartile range of MMI scores from those sites. The interquartile range MMI scores from those thirty-three sites from the Connecticut IC Model was 31-56, representing the difference between the 25th – 75th percentiles (Table 2). Mid IC sites from this study that were within the interquartile range of MMI values from the Connecticut IC Model were considered to be within the expected range of the model. Mid IC sites from this study that were outside the interquartile range of MMI scores were considered to be outside the expected range of the model.

Upstream longitudinal sites and their downstream mid IC pair were compared by plotting MMI scores and percent IC upstream of each site. We also determined taxa density by ecological attribute groups and compared the upstream longitudinal sites to the downstream mid IC pair. Macroinvertebrate densities for each site were calculated as:

$$\text{Individuals/m}^2 = [(\text{Number of individuals in subsample/Number of grids in subsample}) * 56]/2$$

where:

56 is the number of possible grids in a subsample

We averaged duplicate samples or replicate subsamples taken at the same site. The total macroinvertebrate density for each upstream longitudinal site and downstream mid IC pair was then sorted into to one of five ecological attribute groups using taxa identified to the genus level as defined in Gerritsen and Jessup (2007). The five ecological attribute groups were highly sensitive, intermediate sensitive, intermediate tolerant, tolerant, and exotic/invasive taxa. Taxa were assigned to an ecological attribute group based on where the taxon is typically found along the stressor gradient. For example, highly sensitive taxa are typically found in least stressed sites and tolerant and exotic/invasive taxa are typically found in severely stressed sites.

Results

Study Drainage Basin Characteristics

A summary of characteristics of each of the 32 sampling location and drainage basins is provided in Table 1. Drainage basin sizes ranged from 7.25- 62.78 km^2 with a median of 24.14 km^2 and the % IC in the drainage basin ranged from 5.97% -13.70% with a median of 8.76% for the 26 mid IC sites (Figure 3). Most of the mid-IC sites were either 3^{rd} or 4^{th} order using the Strahler (1957) method (Figure 4).

For the five longitudinal sites, drainage basin size ranged from 13.44 – 36.36 km^2 with a median of 27.18 km^2 and the % IC in the drainage basin ranged from 3.10% -7.65% with a median of 5.83%. The Saugatuck River benchmark site is a 4^{th} order stream and the drainage basin size was 53.85 km^2 and the % IC was 4.27%.

Macroinvertebrates

The macroinvertebrate MMI score for the benchmark site on the Saugatuck River for 2006 (62.76) approximated the median value for 10 sample years 1997-2006 (median = 62.71), although there was some variability of the individual metrics from the 2006 sample compared to other years (Figure 5). For example, the Ephemeroptera taxa and Trichoptera taxa metrics were on the high end of the range in 2006 compared to the previous nine years. Conversely, the Plecoptera taxa metric was low compared to previous years.

The median MMI scores of the 26 mid IC sites was 44.05 (range 18.78-53.95) (Figure 6). Individual metric scores varied across the range of scores. The Plecoptera taxa metric generally had low scores whereas the percent dominant genus metric generally had high scores. The five other metrics – Ephemeroptera taxa, Trichoptera taxa, % sensitive taxa, scraper taxa, and BCG taxa biotic index - had scores that ranged towards the central tendency of all possible scores.

Comparisons of MMI scores of mid IC sites from this study with the expected range of MMI scores from the Connecticut IC model showed that eighty percent (21 out of 26) of the mid IC sites had MMI scores that were within the expected interquartile range of 31-56 and 20% (5/26) had MMI scores < 31 (Figure 7). Sites that had MMI scores below the expected range were Long Meadow Pond Brook (Site ID 689), Farm River (Site ID 974), Tenmile River (Site ID 347), Coppermine River (Site ID 894), and Steele Brook (Site ID 514).

An increase in % IC within the same stream resulted in a lower MMI score for each of the five comparisons between upstream longitudinal sites and their downstream mid IC pair (Figure 8). The difference in %IC between the upstream longitudinal sites to downstream mid IC site was similar in the Muddy River (1.52 %) and Hancock Brook (1.8%), although the change in MMI score was greater in Hancock Brook than Muddy River (9% and 3%, respectively). The East Branch Naugatuck River (MMI decreased by 18, %IC increased by 6.08%) and West Branch of the Naugatuck River (MMI decreased by 19, %IC increased by 4.00%) showed the largest decrease in MMI scores of the five comparisons of upstream longitudinal sites with the downstream mid-IC pair.

The West Branch Naugatuck River also showed the greatest percent increase in total macroinvertebrate density (65%) from upstream longitudinal site to downstream mid IC pair sites, followed by the East Branch Naugatuck River (39%) and Muddy River (23%) (Figure 9). Total macroinvertebrate densities decreased in Hancock Brook (58%) and Steele Brook (54%) from longitudinal to mid IC study sites. Two longitudinal sites had highly sensitive taxa present -East Branch Naugatuck River (Site ID 51) and Muddy River (Site ID 1806) in low proportions of the total densities (0.5% and 0.4% respectively). However, the highly sensitive taxa were not present in either downstream mid IC pair - East Branch Naugatuck River (Site ID 54) or Muddy River (Site ID 997). The density of intermediate sensitive taxa was higher at upstream longitudinal sites compared to downstream mid IC study sites in all five comparisons. The upstream longitudinal site on the West Branch Naugatuck River (Site ID 357) had the highest proportion of sensitive and intermediate sensitive taxa (28% of total taxa) followed by the East Branch Naugatuck River, Site 51 (14% of total taxa), of all sites evaluated in the longitudinal analysis. These two sites (Site ID 357 and 51) also had the lowest proportion of intermediate tolerant and tolerant taxa (71% and 86% respectively). The Steele Brook mid IC site (Site ID 514) had the lowest proportion of sensitive and intermediate sensitive taxa (1% of total taxa) and the highest proportion of intermediate tolerant and tolerant taxa (98% of total taxa). Steele Brook also had the greatest percent decrease in intermediate sensitive taxa (96%) from the upstream longitudinal site (Site ID 697) to the downstream mid IC site (Site ID 514).

Discussion

One of the biggest challenges facing natural resource agencies in Connecticut and other geographic areas with growing urban footprints is to explain the science, bridge the gap where science is uncertain, and influence policy to protect rivers and streams. We believe the IC model provides a conceptual framework to foster better communication between scientists and policy makers that make land use decisions. This study provides supporting evidence that enhances the scientific foundation of using a simple surrogate measure such as IC to demonstrate the potential effects of land use change on stream health in Connecticut.

The data collected in this study are representative of typical conditions for streams in Connecticut. MMI scores from Saugatuck River benchmark site collected in 2006 approximated the median of the previous nine years. The range of variability among individual metrics and the resultant MMI score (i.e. < 20 MMI points) is typical of the natural variability from sites in Connecticut sampled in multiple years (Gerritsen and Jessup, 2007). The nine year period of record provides sufficient variability in flow and weather conditions to judge whether 2006 was a typical year, or influenced more strongly by extreme environmental conditions (Figure 10).

One of the study goals was to relate the results of this study to the previous Connecticut IC model (Bellucci, 2007) and to fill in some of the gaps in the mid IC range of the data. To achieve this goal, thirty two sites sampled from this study were pooled with the sites that comprised the initial Connecticut IC Model (N=125). The results of the pooled sites (N= 157) fit the scatter plot (Figure 11) and strengthen the relationship between IC and macroinvertebrate communities from Connecticut streams by filling in data gaps from sites with medium levels of IC.

This study provides further support that IC can be a very good predictor of the macroinvertebrate community as measured by the MMI in Connecticut. MMI scores were higher above clusters of IC and decreased below IC clusters in the same watershed for all five of the longitudinal comparisons. In addition the longitudinal analysis by grouping taxa into ecological attribute groups suggests there may be shifts in the biological community at certain levels of percent IC. Longitudinal sites with lowest percent IC in this study (East Branch Naugatuck River (Site ID 51, % IC 3.38) and West Branch Naugatuck River (Site ID 357, %IC 3.1), had lower total densities but higher proportions of sensitive taxa and lower proportions of tolerant taxa. In contrast the Steele Brook mid IC study site (Site 514), which had the highest percent IC in this study (13.7%), had a very low proportion of sensitive taxa.

We have shown that we can reasonably predict MMI scores by using 6-14% IC to estimate an expected MMI using the interquartile range of MMI scores. This idea can be related back to the initial IC conceptual model (Figure 1) and we further quantified this relationship by pooling the 125 study stream from previous work in Connecticut (Bellucci 2007) with the 32 sites from this study. We used the percent IC upstream of each of these 157 sites to make three general land use groups - rural (<4.99 % IC), mixed (5.00-11.99 % IC), and urban (>12 % IC). We then used the interquartile range of MMI scores for the sites that comprised each land use category to approximate a reasonable expected condition for streams in Connecticut (Figure 12). This information can be used as another tool to communicate the expected biological condition and stream health for streams to land use decision makers. One simple graphic, communicates a reasonable expectation of stream health and can be incorporated into a map using GIS (Figure 13).

This analysis is important because macroinvertebrates provide the primary measure of stream health for regulatory programs in Connecticut. The CTDEP use macroinvertebrates as one of the measures for assessing aquatic life for Federal Clean Water Act (CWA) 305(b) reporting and

Section 303(d) impaired water listing. Streams that are considered “impaired” for aquatic life are placed on the 303(d) list of impaired waters and require the state to develop TMDLs per CWA requirements. Data from this study show that the biological potential of streams in Connecticut differs with land use and should be considered when setting realistic biological goals (Booth, 2005: Davies and Jackson, 2006; Wickham and Norton, 2008).

Further, this analysis by land use type (Figures 12 and 13) may help with the identification of potential stressors for those streams that fall outside of the expected interquartile range. It follows that the stressors associated with each of these land use types may be different or cumulative. Rural streams that fall outside of the expected condition could be affected by stressors related to water quantity, agricultural land use, and perhaps events such as spills due to motor vehicle accidents. Urban streams usually present the most complex array of potential stressors, several of which are related to the amount of impervious cover (e.g. altered hydrology, increase in pollutants loads, temperature increases, and decreased habitat quality). Other stressors such as point source and legacy land uses also become more prevalent in urban settings. Streams in the mixed land use category have stressors that most likely fall in between rural and urban land use.

In this study, there were 5 sites with MMI scores below the expected range -Long Meadow Pond Brook (Site ID 689), Farm River (Site ID 974), Tenmile River (Site ID 347), Coppermine River (Site ID 894), and Steele Brook (Site ID 514). These sites would be good locations for further work to investigate why they are not meeting their biological potential. This study used land cover coefficients and 30 meter pixel resolution land cover data to calculate IC, which is appropriate for a state wide analysis such as the current study. Further investigation of these sites that are outside of the expected range could include more detailed GIS analysis of additional watershed stressors, in-depth field investigations and direct measures of impervious surfaces to help characterize potential reasons for these low MMI scores. For example, other studies found that the amount of effective or connected impervious cover may be a better measure to determine the impact of urban runoff (Alley and Veenhuis, 1983).

We also recognize the potential to use the IC conceptual model (Figure 1) to investigate relatively undisturbed sites in Connecticut. Much of the work with assessing aquatic life in streams in Connecticut has historically been focused on “urban streams” that fall within the “mitigation” category of our conceptual model diagram. This study provides a summary of the “streams of hope” or “active management” category and provides some insight to the characteristics of these streams. An extension of this study would be to use GIS to select streams in the “best” stream class and “preservation” management category to document the characteristics of these sites and test whether the methodology used in this study to predict the MMI range can predict the MMI scores from smaller streams on the low end of the IC gradient. This would be an especially important extension of this study because small 1^{st} to 2^{nd} order streams comprise approximately 75% of the river miles in Connecticut and the ecology of these streams is important to downstream water quality (Alexander *et al*., 2007) and ecological integrity (Freeman *et al*., 2007).

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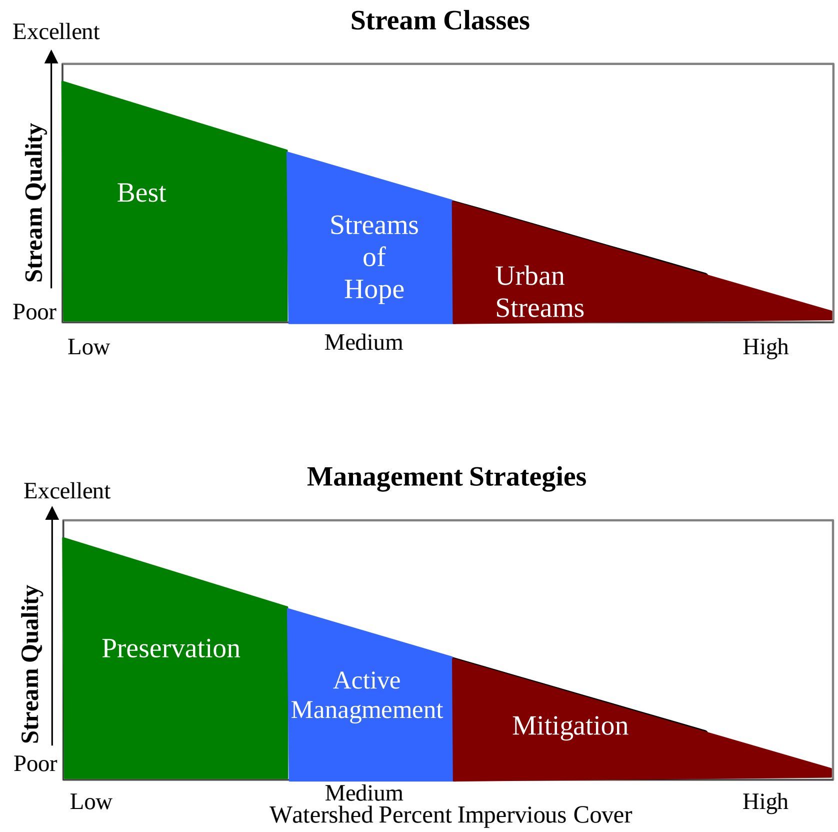

FIGURE 1. Conceptual Model of the Effect of Impervious Cover on Stream Quality. Watershed percent impervious cover as a conceptual model for stream classes (top) potential management strategies (bottom) for streams.

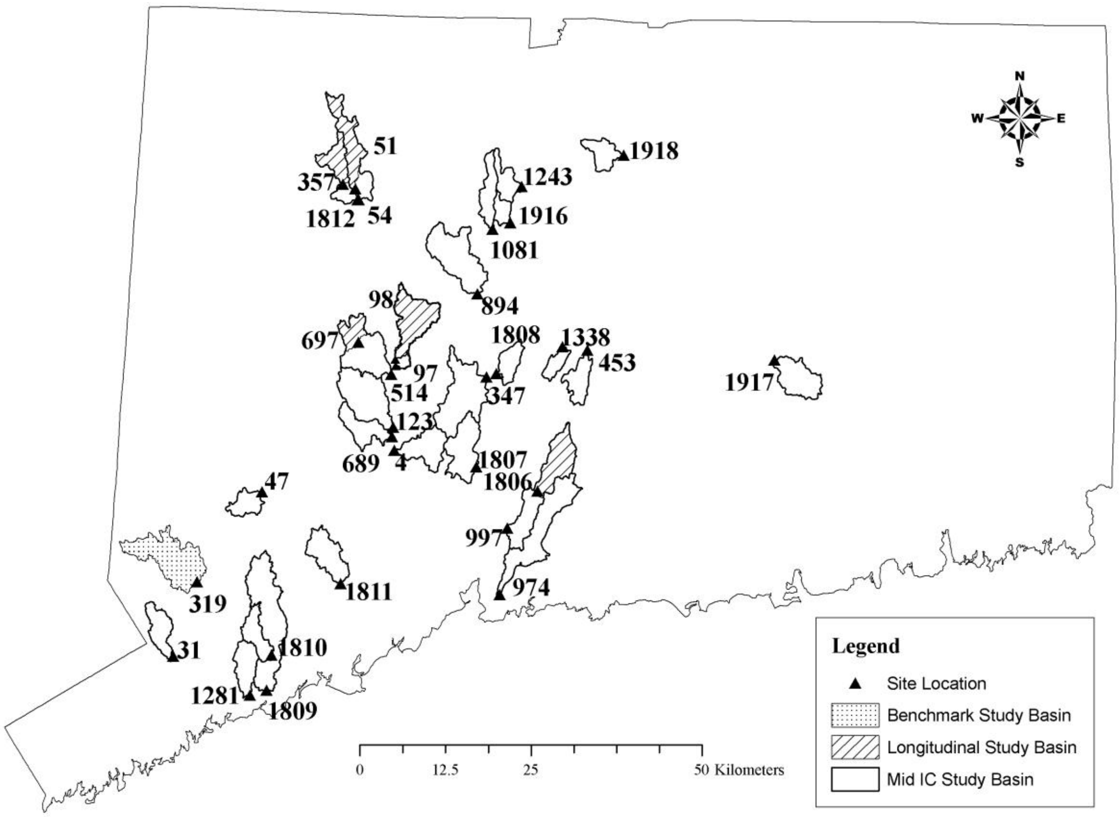

FIGURE 2. Sampling Site Locations and 32 Study Drainage Basins. See Table 1 for further description site locations and drainage basin characteristics.

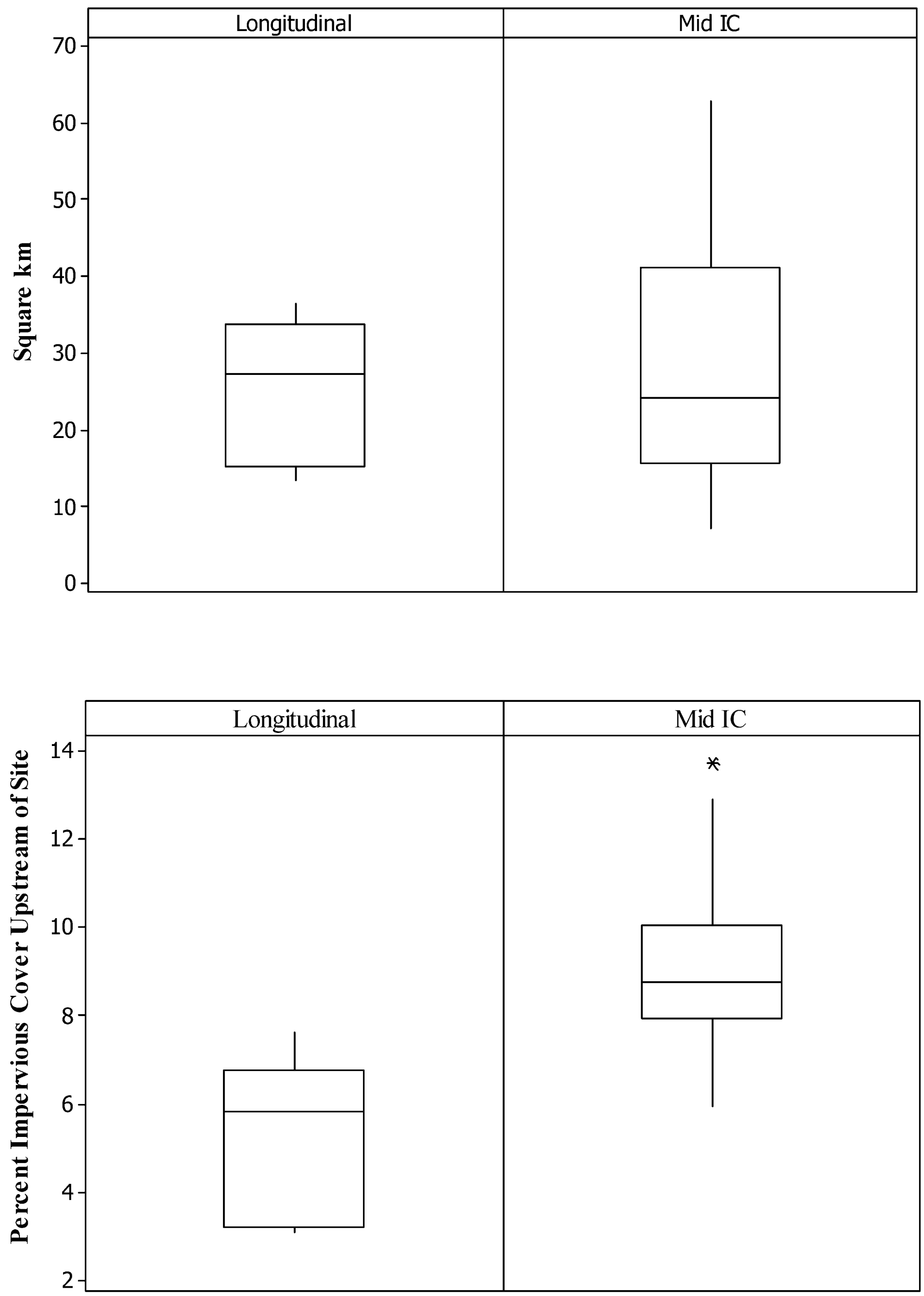

FIGURE 3. Drainage Basin Size and Percent Impervious Cover. Boxplots of drainage basin size (top) and percent impervious cover upstream (bottom) of 26 mid IC sites and five longitudinal sites. An asterisk identifies a value that is 1.5 times the interquartile range.

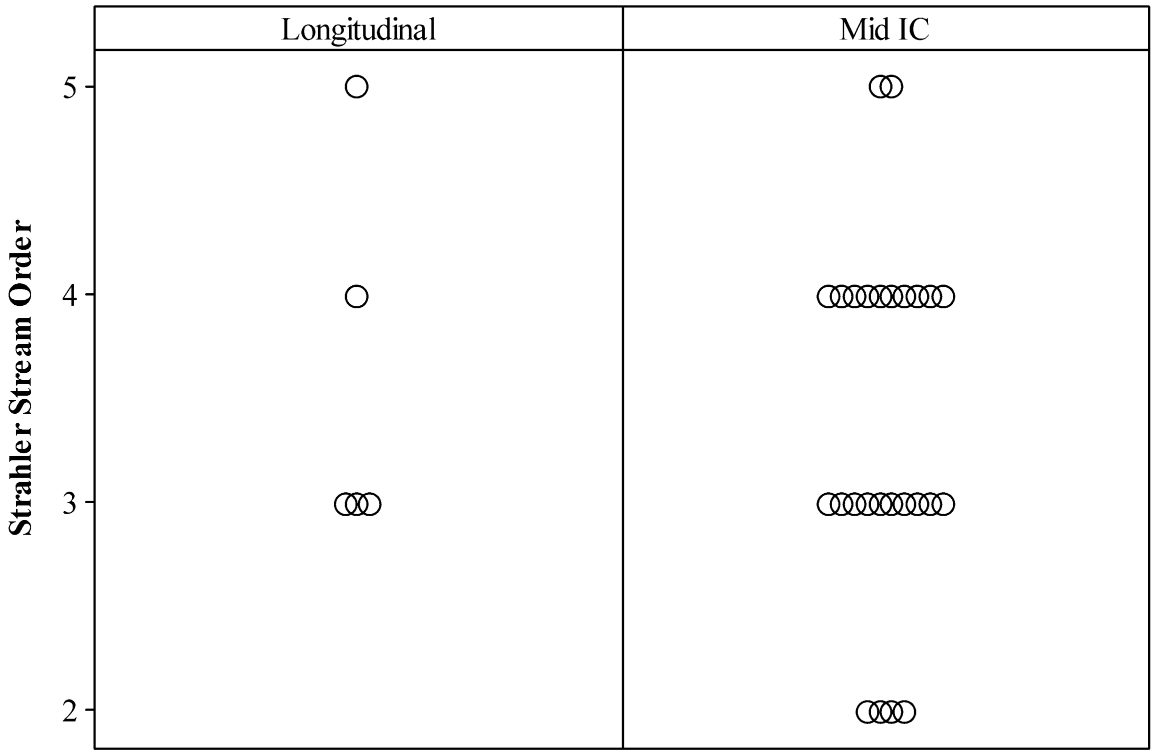

FIGURE 4. Stream Order of Study Sites. Dot plots of Strahler stream order for 26 mid IC sites and five longitudinal site.

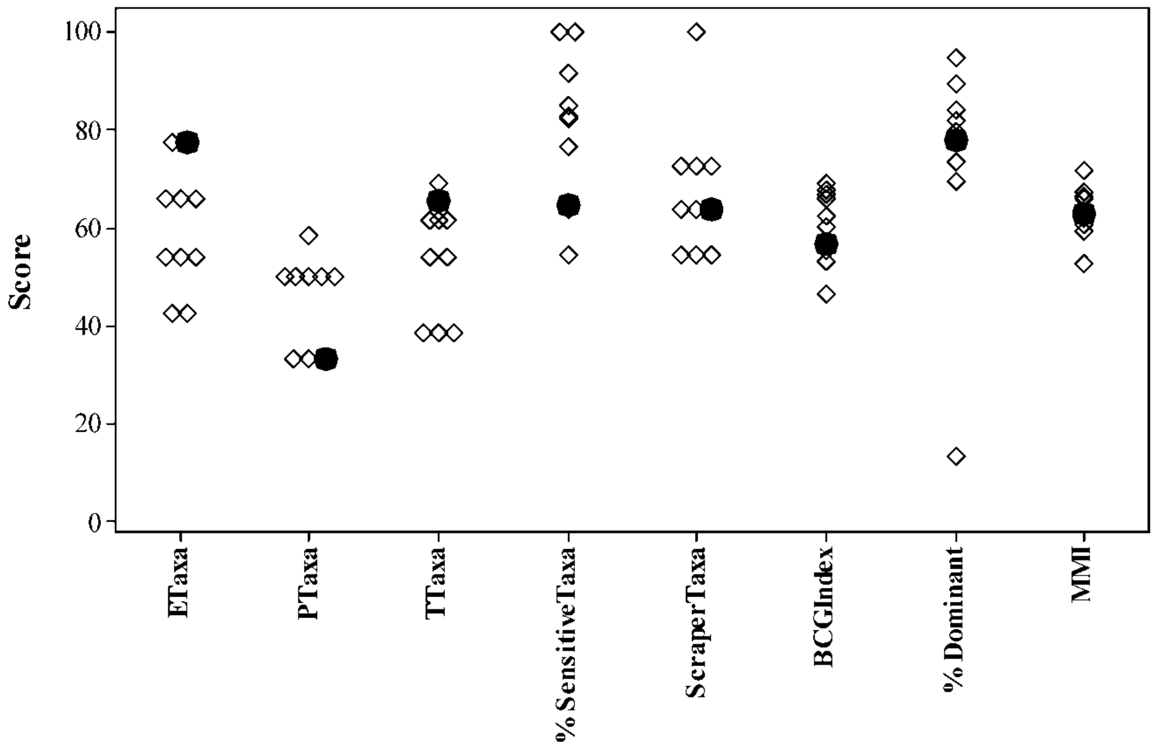

FIGURE 5. Macroinvertebrate Metrics and Multimetric Index (MMI) for the Saugatuck River Benchmark Site from Samples Collected 1997-2006. Solid circle represents 2006 sample year and open triangles represent 1997-2005. ETaxa is Ephemeroptera taxa (scoring adjusted for watershed size), PTaxa is Plecoptera taxa, TTaxa is Trichoptera taxa, %SensTaxa is percent sensitive EPT (scoring adjusted for watershed size), ScrTaxa is scraper taxa, BCGIndex is biological condition gradient taxa biotic index, and %Dom is percent dominant genus.

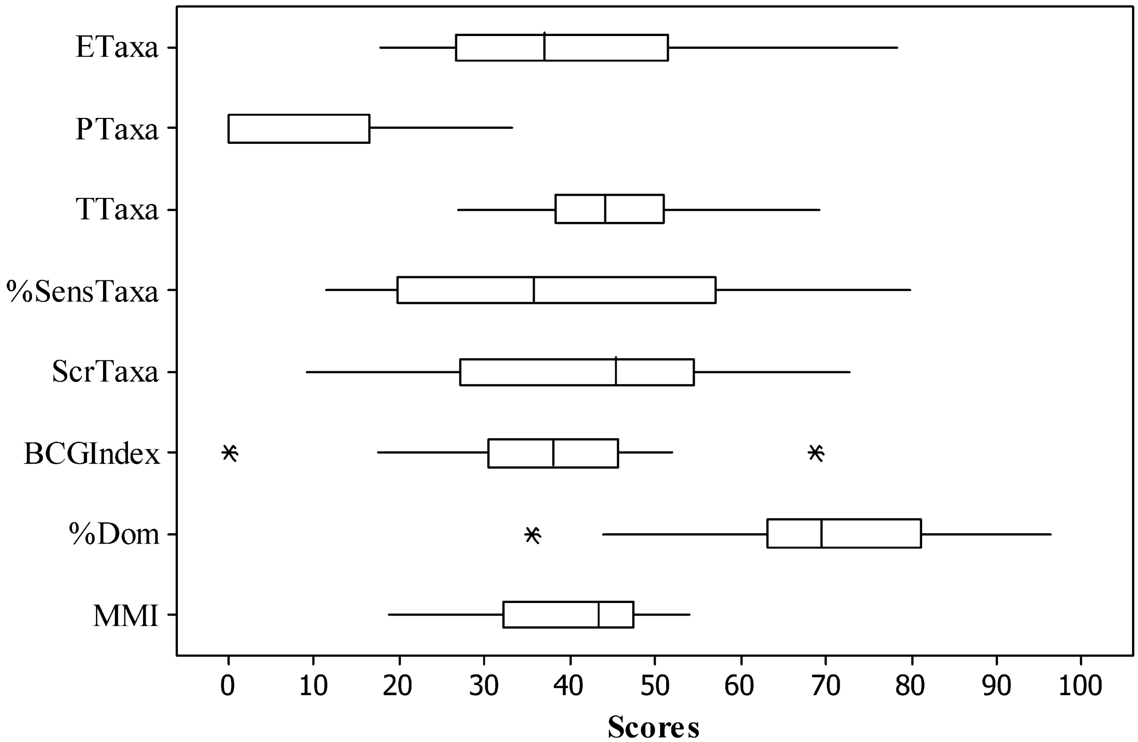

FIGURE 6. Macroinvertebrate Metrics and Multimetric Index (MMI) for 26 Mid IC Sites. Boxplots summarize the scores from seven macroinvertebrate metrics and MMI for 26 mid IC sites. ETaxa is Ephemeroptera taxa (scoring adjusted for watershed size), PTaxa is Plecoptera taxa, TTaxa is Trichoptera taxa, %SensTaxa is percent sensitive EPT (scoring adjusted for watershed size), ScrTaxa is scraper taxa, BCGIndex is biological condition gradient taxa biotic index, and %Dom is percent dominant genus. An asterisk identifies a value that is 1.5 times the interquartile range.

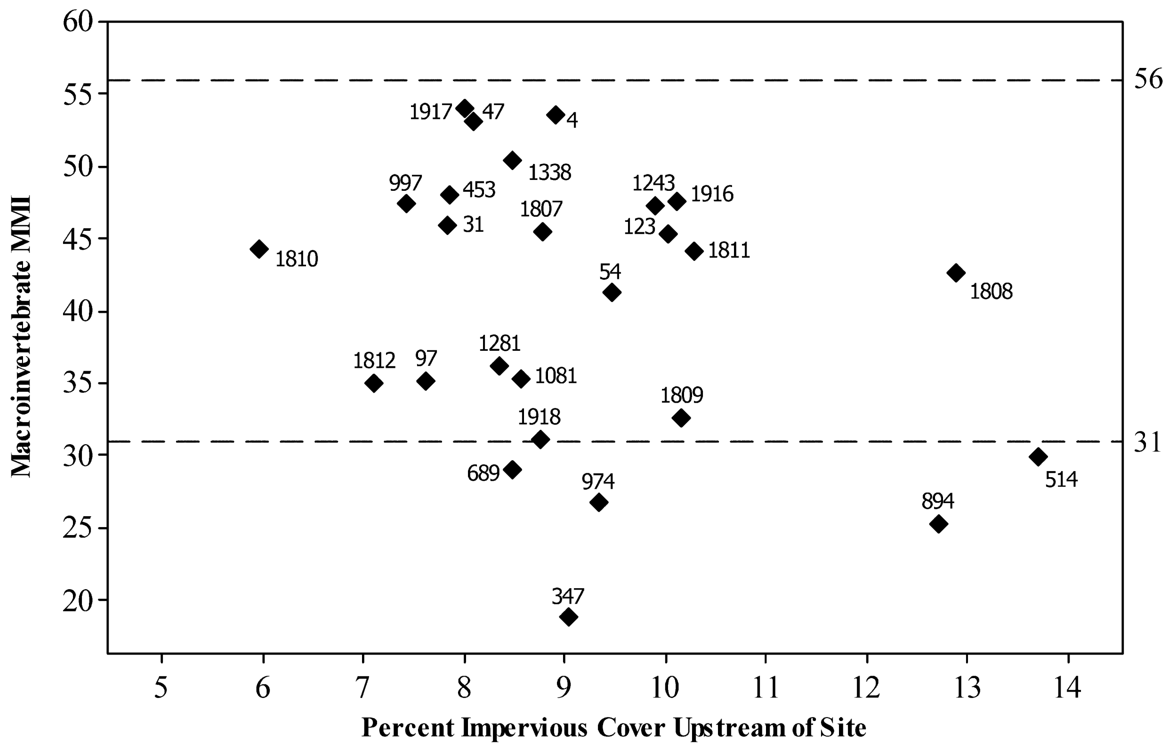

FIGURE 7. Macroinvertebrate Multimetric Index (MMI) and Percent Impervious Cover for 26 Mid IC Study Sites. The expected MMI scores for sites that range 6- 14% impervious cover are 31-56 (interquartile range of predictive Connecticut IC model). Site numbers correspond to locations described in Table 1 and Figure 2.

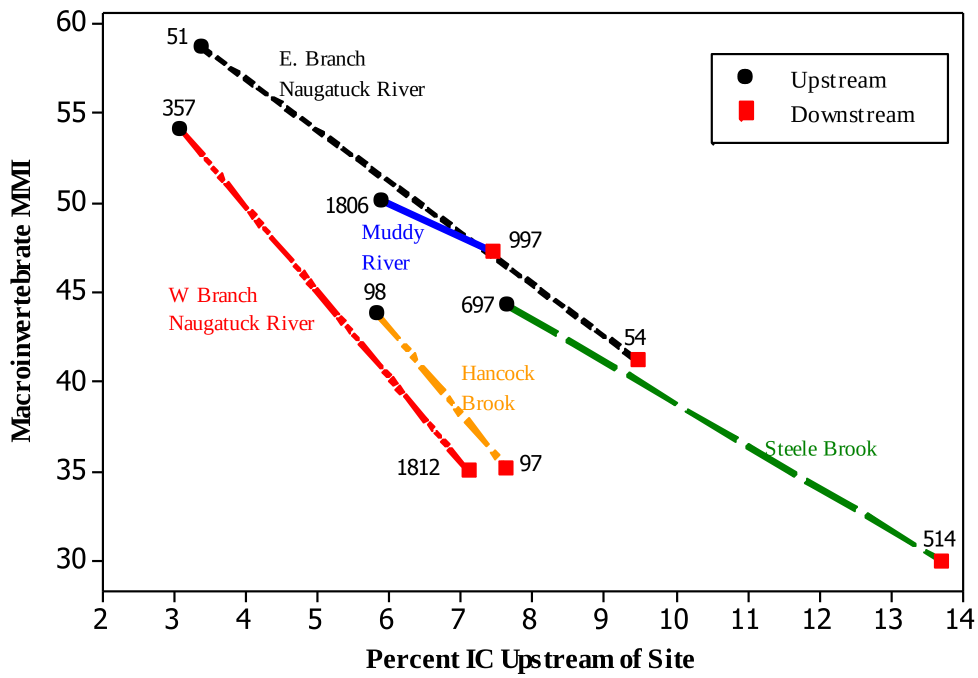

FIGURE 8. Macroinvertebrate Multimetric Index Scores (MMI) and percent impervious cover (IC) upstream of the study site from two locations on the same stream. Each line represents a different stream and connects upstream longitudinal sites (black circle) to downstream mid IC site (red square). Sites numbers correspond to locations described in Table 1 and Figure 2.

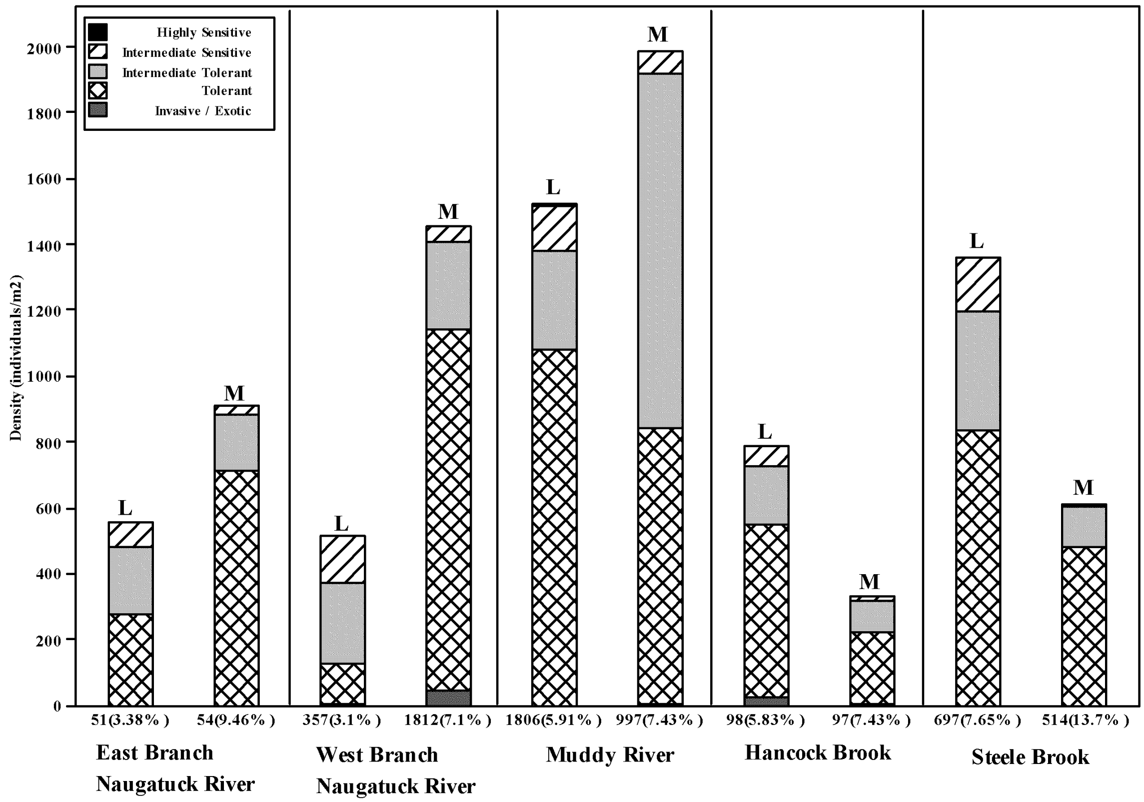

FIGURE 9. Macroinvertebrate Taxa Ecological Groups. Average macroinvertebrate density (individuals/m^2) at upstream longitudinal sites (L) and downstream mid IC study sites (M) by taxa ecological attribute group. Taxa ecological attribute groups range from highly sensitive taxa (top of the bar) to invasive/exotic taxa (bottom of the bar). The x axis is the site number (identified in Table 1 and Figure 2) with the percent impervious cover upstream of the site in parenthesis.

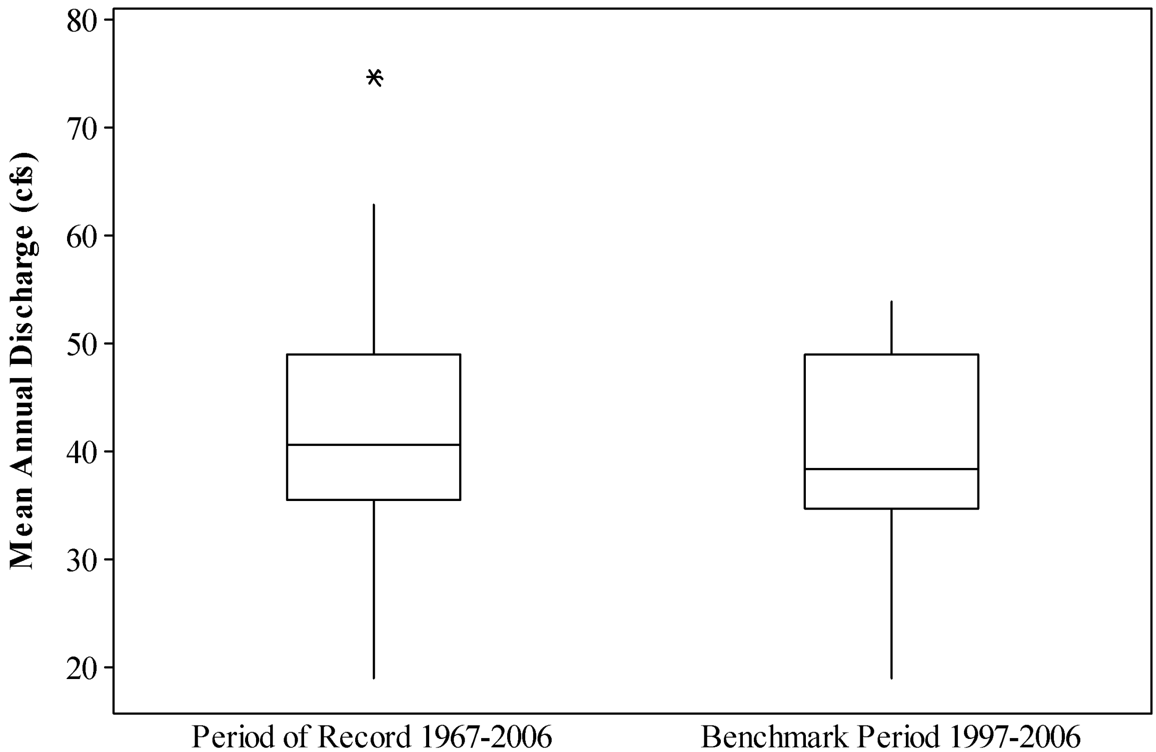

FIGURE 10. Streamflow Conditions at Benchmark Site. Mean annual discharge in cubic feet per second (cfs) at the Saugatuck River benchmark site for 1967– 2006 and macroinvertebrate benchmark period 1997-2006. Stream discharge data are from USGS gage number 01208990, Saugatuck River near Redding, Connecticut.

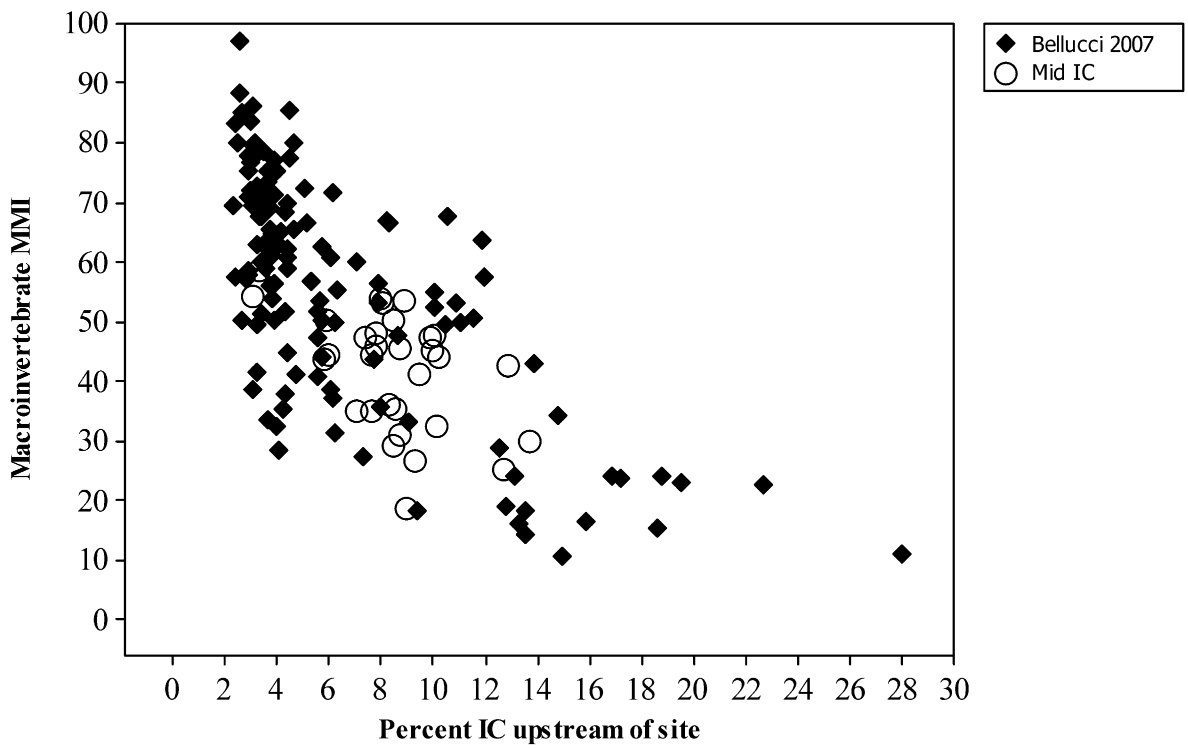

FIGURE 11. Macroinvertebrate Multimetric Index (MMI) Scores. MMI and percent impervious cover for 125 sites in Connecticut (Bellucci 2007) and 32 sites from this study (Mid IC).

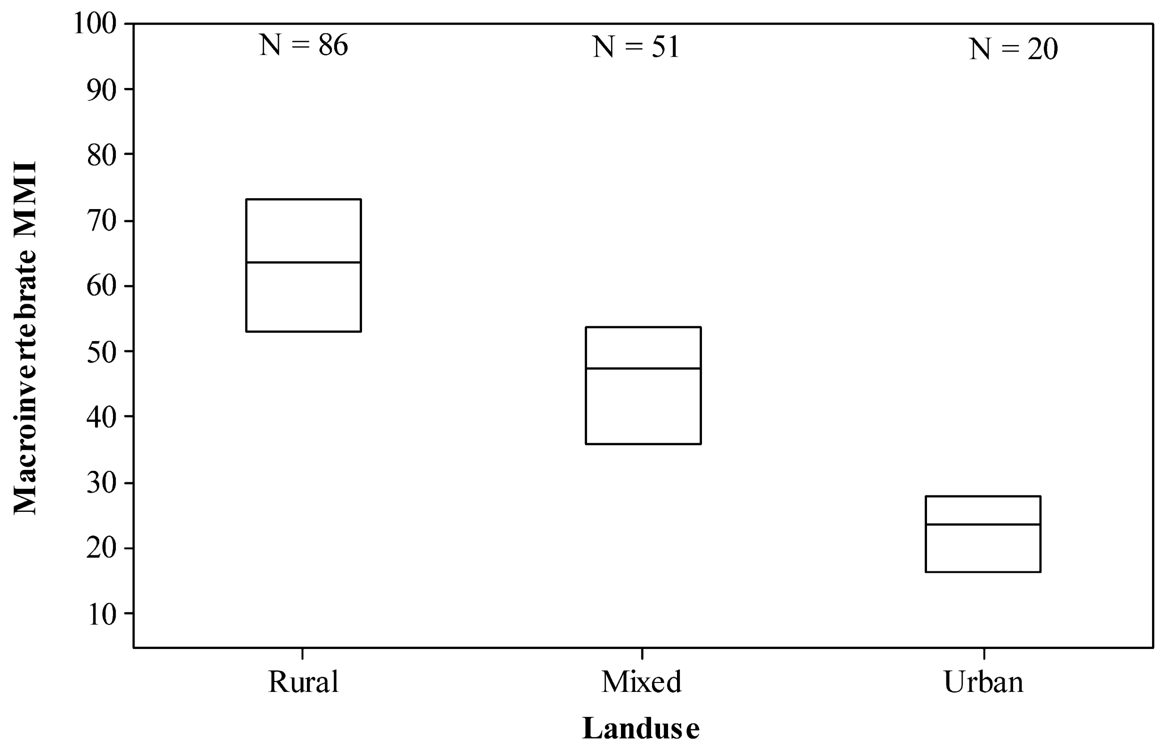

FIGURE 12 . Macroinvertebrate Multimetric Index (MMI) Scores by Land Use Type. Expected MMI scores for three land use categories as shown by the interquartile range (75th-25th percentile) of sites in each category– rural =53-73;mixed=36-53;urban=16-28. Interquartile ranges and medians (horizontal line) were calculated from a total of 157 MMI scores grouped by land use (rural N=86; mixed N=51; urban N=20). Rural land use was defined as <4.9% impervious cover, mixed land use was defined as 5.0 -11.9% impervious cover and urban land use was defined as >12% impervious cover.

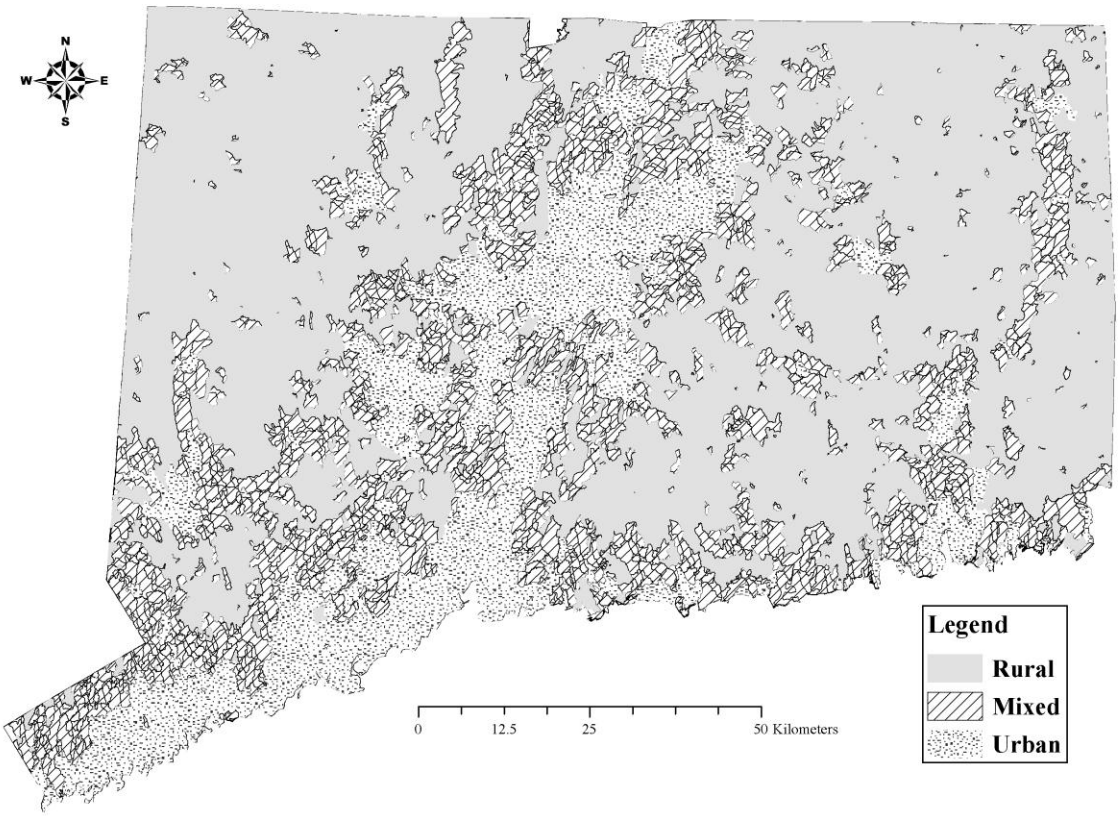

FIGURE 13. Land Use in Connecticut and Expected Macroinvertebrate Multimetric (MMI) Index Scores. Three land use categories in Connecticut were defined - rural land use <4.9% impervious cover; mixed land use 5.0 -11.9% impervious cover; and urban land use >12% impervious cover. Impervious cover was derived using the Impervious Surface Analysis Tool and 2002 land cover data. Expected macroinvertebrate MMI scores for these three land use categories are shown in Figure 12 – rural =53-73, mixed=36-53, urban=16-28.

TABLE 1. Study Site Locations. Site location and drainage basin characteristics of 32 study sites grouped by mid IC sites, longitudinal sites, and benchmark site. Site ID's are identified spatially in Figure 2.

Site ID	Stream Name	Town	Latitude (Decimal degrees)	Longitude (Decimal degrees)	Sample Date	Strahler Stream Order	Drainage Basin (km^2)	Drainage Basin IC %
				Mid IC Sites				
4	Beacon Hill Brook	Naugatuck	41.4684	-73.0519	10/6/2006	3	26.39	8.90
31	Comstock Brook	Wilton	41.1961	-73.4354	9/20/2006	4	18.96	7.83
47	Deep Brook	Newtown	41.4131	-73.2823	10/11/2006	4	13.81	8.10
54	East Branch Naugatuck River	Torrington	41.7977	-73.1158	10/5/2006	4	36.49	9.46
97	Hancock Brook	Waterbury	41.5799	-73.0497	10/6/2006	2	39.83	7.63
123	Hop Brook	Naugatuck	41.4987	-73.0537	10/6/2006	3	45.03	10.02
347	Ten Mile River	Southington	41.5655	-72.8905	9/27/2006	3	52.28	9.03
453	Sawmill Brook	Middletown	41.6008	-72.7141	9/21/2006	4	18.00	7.85
514	Steele Brook	Waterbury	41.5687	-73.0574	10/19/2006	3	30.64	13.70
689	Long Meadow Pond Brook	Naugatuck	41.4864	-73.0556	10/6/2006	4	21.89	8.48
894	Coppermine Brook	Bristol	41.6737	-72.9060	10/11/2006	3	48.16	12.72
974	Farm River	East Haven	41.2791	-72.8672	9/27/2006	4	50.77	9.33
997	Muddy River	North Haven	41.3668	-72.8543	9/27/2006	4	54.02	7.43
1081	Roaring Brook	Farmington	41.7594	-72.8808	10/5/2006	3	18.52	8.57
1243	Nod Brook	Avon	41.8158	-72.8294	10/11/2006	2	15.07	9.89
1281	Sasco Brook	Fairfield	41.1457	-73.3012	9/20/2006	3	20.22	8.35
1338	Belcher Brook	Berlin	41.605	-72.7577	9/21/2006	4	9.27	8.48
1807	Willow Brook	Hamden	41.4472	-72.9083	9/27/2006	2	33.27	8.77
1808	Misery Brook	Southington	41.5699	-72.8733	10/11/2006	3	14.16	12.89
1809	Mill River	Fairfield	41.1521	-73.2726	9/20/2006	3	62.78	10.16
1810	Cricker Brook	Fairfield	41.1984	-73.2647	9/20/2006	5	18.10	5.97
1811	Means Brook	Shelton	41.2931	-73.1442	10/11/2006	4	27.15	10.28
1812	West Branch Naugatuck River	Torrington	41.798	-73.1177	10/5/2006	4	7.25	7.10
1916	Thompson Brook	Avon	41.7681	-72.8497	10/11/2006	5	8.55	10.11
1917	Meadow Brook	Colchester	41.5871	-72.3868	9/21/2006	2	28.78	8.00
1918	Mill Brook	Windsor	41.8569	-72.6501	9/21/2006	3	15.72	8.75

TABLE 1. continued

Site ID	Stream Name	Town	Latitude (Decimal degrees)	Longitude (Decimal degrees)	Sample Date	Strahler Stream Order	Drainage Basin (km^2)	Drainage Basin IC %
			Longitudinal Sites					
51	East Branch Naugatuck River	Torrington	41.8122	-73.1221	10/5/2006	4	27.18	3.38
98	Hancock Brook	Waterbury	41.5885	-73.0503	10/6/2006	3	36.36	5.83
357	West Branch Naugatuck River	Torrington	41.8181	-73.1441	10/5/2006	5	16.84	3.10
697	Steele Brook	Watertown	41.6105	-73.1153	10/19/2006	3	13.44	7.65
1806	Muddy River	Wallingford	41.4151	-72.8012	9/27/2006	3	31.19	5.91
			Benchmark Site					
319	Saugatuck River	Redding	41.29447	-73.3948	10/4/2006	4	53.85	4.27

TABLE 2. Expected Macroinvertebrate Multimetric Index (MMI) Statistics. The expected MMI statistics for the 26 mid IC study sites were predicted using 6-14% impervious cover from 33 sites in Bellucci (2007). The MMI interquartile range (25^{th}-75^{th} percentile) was used in this study.

Statistic	MMI	Percent IC	Drainage Basin Size (km^2)
N	33	33	33
Minimum	14.24	6.05	15.30
Maximum	71.66	13.55	108.02
25^{th} Percentile	31.41	7.33	22.07
50^{th} Percentile	49.81	9.07	37.45
75^{th} Percentile	56.38	11.53	50.01