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# **Fox River Watershed Investigation: Stratton Dam to the Illinois River Phase II**

**Analyses of Biological Data**

by  
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**Prepared for**  
**Fox River Study Group, Inc.**

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Institute of Natural Resource Sustainability  
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Champaign, Illinois



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Report presented to the  
Fox River Study Group, Inc.

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I L L I N O I S



## **Abstract**

This report summarizes biological data collected in the Fox River watershed. It describes database development and data sources available for the study area, the Fox River watershed from Stratton Dam to the Illinois River. Biological evaluation using fish and macroinvertebrate indices and habitat data analysis are included in this report.

The structure of the existing water and sediment quality database, FoxDB, was expanded to include individual biological samples and information on species abundance. The structure was designed to help calculate various metrics describing fish and macroinvertebrate communities in indexes of biotic integrity. The database was populated with biological and habitat information collected in the study area, including 86 macroinvertebrate samples from 63 monitoring stations and 201 fish samples from 102 stations.

The Macroinvertebrate Biotic Index (MBI) and selected metrics of the revised Illinois Index of Biotic Integrity (IBI) were evaluated for changes in flow regime (free-flowing and impounded), stream size (mainstem and tributaries), and spatial location (upper more urbanized part and lower rural part of the study area). Most biological indicators imply the impairment of mainstem sites, especially in impounded portions of the river, and suggest higher impairment in the upper urbanized part of the watershed.

## **Acknowledgments**

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Any opinions, findings, conclusions, or recommendations expressed in this report are those of the author and do not necessarily reflect those of the Fox River Study Group or the Illinois State Water Survey.

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## Introduction

The Fox River watershed is located in Wisconsin and Illinois. The Illinois State Water Survey (ISWS) is participating in a study of the Fox River watershed within Illinois, below Stratton Dam to the confluence of the Fox and Illinois Rivers. This report is one of a series of reports on the Fox River Watershed Investigation prepared by the ISWS.

The intent of this report is to provide an analysis of the available biological data that serves as indicators of water quality. The analyses of biological data are part of an ongoing investigation of water quality issues identified by the Illinois Environmental Protection Agency (IEPA). This work is being conducted for and in consultation with the Fox River Study Group, Inc. (FRSG). The report does not review biological or habitat data from a regulatory point of view, but rather looks for trends and spatial relationships. This analysis complements the ongoing investigation of the Fox River watershed water quality.

The biological integrity of stream and river reaches is typically determined by evaluating the composition of macroinvertebrate or fish communities living in the reach. The presence/absence of macroinvertebrate or fish species and their abundance is influenced by habitat, water and sediment quality, flow regime, availability of food (energy sources), and biotic factors (e.g., competition, predation, or diseases). The challenge is to find a link between these characteristics and aquatic communities. Understanding the linkage can ultimately provide guidance as to what variables society can modify to maximize desirable stream ecology.

## Project Overview

The Fox River in northeastern Illinois is the focal point of many communities along the river, providing an aesthetically pleasing area and opportunities for fishing, canoeing, and boating. The Fox River is also a working river. Two major cities, Elgin and Aurora withdraw water for public water supply, and the river also serves as a receptor for storm water and treated waste water. This highly valued river, however, has been showing increasing signs of impairment.

In response to local concerns about the Fox River water quality, the FRSG organized in 2001. The FRSG comprises a diverse group of stakeholders representing municipalities, county government, water reclamation districts, and environmental and watershed groups from throughout the watershed. The goal of the FRSG is to address water quality issues in the Fox River watershed and assist with implementing activities to improve and maintain water quality. The FRSG has initiated activities to more accurately characterize the water quality of the Fox River, including data collection and preparation of comprehensive water quality models.

In the *Illinois Water Quality Report 2000*, the IEPA listed parts of the Fox River in McHenry and Kane Counties and part of Little Indian Creek as impaired. The 2002 IEPA report (IEPA, 2002) listed the entire length of the Fox River in Illinois as impaired, as well as Nippersink, Poplar, Blackberry, and Somonauk Creeks, and part of Little Indian Creek. The IEPA has included the Fox River and these tributaries on their list of impaired waters, commonly

called the 303(d) list (IEPA, 2003). The latest report available during this study (IEPA, 2006) continues to list the entire length of the Fox River, as well as Nippersink Creek, Tyler Creek, Crystal Lake outlet, Poplar Creek, Ferson Creek, and Blackberry Creek as impaired. The most prevailing potential sources for listing were hydromodification and flow regulation, urban runoff, and combined sewer overflows. The most prevailing potential causes for listing were issues related to flow alterations, habitat, sedimentation/siltation, dissolved oxygen, suspended solids, excess algal growth, fecal coliform bacteria, and PCBs. A suite of water quality models is being developed to characterize the various sources and causes of impairment.

## Background Information

A review of water quality data and previous studies (McConkey et al., 2004) led to the selection of the following constituents for detailed modeling: suspended solids, nitrogen (and its forms), phosphorus (and its forms), fecal coliform bacteria, dissolved oxygen (DO), pH, and algae, including supporting parameters such as temperature and organic matter (Biochemical Oxygen Demand or BOD). Table 1 provides an overview of water quality issues in the Fox River by identifying monitoring sites where measured values exceeded water quality standards or recommended values. Table 2 lists critical times and conditions when noncompliance with the IEPA standards typically occurred.

**Table 1. Water Quality Issues Identified at Selected Locations (McConkey et al., 2004)**

<u>Location</u>	<u>Probabilistic noncompliance</u>			<u>Presence of samples with substandard values</u>	
	<u>Ammonia nitrogen</u> ( <u>Chronic quotient &gt;1</u> )	<u>Fecal Coliform</u> ( <u>&gt;400/100 mL</u> )	<u>Phosphorus</u> ( <u>&gt;0.076 mg/L</u> )	<u>DO</u> ( <u>&lt;5 mg/L</u> )	<u>pH</u> ( <u>&gt;9</u> )
Johnsburg			X	X	
Route 176			X	X	
Algonquin	X	X	X	X	X
South Elgin		X	X	X	X
Geneva		X	X	X	
Montgomery		X	X		X
Oswego			X	X	X
Yorkville		X	X		X
Ottawa	X	X	X		X

**Notes:**

The phosphorus value is a guideline, not a water quality standard.  
An “X” signifies water quality problems.

**Table 2. Critical Times and Conditions Identified for Selected Constituents in the Fox River Watershed (McConkey et al., 2004)**

<u>Constituent</u>	<u>Critical time</u>	<u>Critical conditions</u>
DO	Summer (seasonal variation) Prior to sunrise (diurnal variation)	High temperature, low flow Impoundment, algae
Algae	Summer	Low flow, nutrient enrichment
Total nitrogen	Concentration fairly constant	Both high and low flows
Ammonia	Varies, typically summer (lower standard)	Low flow, high temperature, and high pH (effects standard)
Nitrate/nitrite	Spring	Precipitation events
Total phosphorus	Summer	Low flow (concentration) High flow (load)
Suspended solids	Summer (concentration) Spring to early summer (load)	High flow
pH	Varies	Low flow, algae
Fecal coliform	Summer (lower standard)	No clear pattern

## **Biological Data Sources**

### **IEPA Data**

Biological and habitat data from the Fox River watershed were collected mainly by the IEPA as part of their Intensive Sampling Program. The IEPA conducts intensive basin-wide surveys on a five-year rotation basis in cooperation with the Illinois Department of Natural Resources (IDNR). These intensive surveys are a major source of information for annual 305(b) assessments required by the Clean Water Act. Water chemistry and biological data (fish and macroinvertebrates) and qualitative and quantitative instream habitat information, including stream discharge, are collected to characterize stream segments within the basin, identify water quality conditions, and evaluate aquatic life use impairment. Fish tissue contaminant and sediment chemistry sampling also are conducted to screen for the accumulation of toxic substances (IEPA, 2007).

The IEPA provided macroinvertebrate samples collected at 26 sites in the study area during its intensive sampling program, including 16 sites in 1996 and 20 sites in 2002 (10 sites with 20-jab method, 7 sites with hand-picked method, and 7 sites with Hester-Dandy method). Nine sites were located on the Fox River mainstem and 17 sites were on tributaries. Water and sediment quality data associated with this sampling were imported to the FoxDB during Phase I of the Fox River Watershed Investigation (McConkey et al., 2004). The Fox River watershed was sampled again in summer 2007; however, the results of this survey were not available during the preparation of this report.

### **Max McGraw Wildlife Foundation (MMGWF) Data**

In a special study (Santucci and Gephard, 2003), the Max McGraw Wildlife Foundation (MMGWF) collected and evaluated biological and habitat data on the Fox River mainstem to investigate the effect of impoundments. Samples were collected from reaches characterizing different flow regimes: directly above and below each of the 15 Fox River dams and at 10 mid-segment locations in impounded (MD IMP) and free-flowing (MD FF) areas between dams. The IDNR- and IEPA-approved methodologies were used to sample fish, macroinvertebrates, and aquatic habitat during July through early September 2000 at 40 stations within the study area. Water and sediment quality data associated with this sampling effort were imported to the FoxDB during Phase I of the Fox River Watershed Investigation (McConkey et al., 2004).

### **USGS Data**

Biological data were collected by the U.S. Geological Survey (USGS) as part of an urban gradient study (Adolphson et al., 2002). Benthic macroinvertebrate community collections followed USGS National Water-Quality Assessment NAWQA methods (Cuffney et al., 1993). In each reach, a benthic macroinvertebrate sample was collected from either cobbles or submerged branches (woody debris). At four sites, two samples were collected, one from cobble and the other from submerged branches. When a cobble riffle was present, a Hess sampler was used to collect macroinvertebrates. Macroinvertebrate and fish samples were collected at 20 sites in the Fox River watershed, 15 of which are within the study area. All of these sites are on the tributaries to the Fox River.

## Characterization of Sites

### Macroinvertebrates

The Macroinvertebrate Biotic Index (MBI) is commonly used in Illinois to evaluate stream impairment. The MBI is a weighted tolerance index used by the IEPA to assess surface waters. Values range from 0 to 10 with higher values signifying more tolerant organisms and less desirable conditions. MBI values  $\geq 7.5$  represent benthic communities with moderate or few taxa, absent or few intolerant organisms, and a predominance of tolerant forms (Bertrand et al., 1996). The IEPA uses a threshold of 5.9 to identify streams with no impairment; sites with an MBI between 5.9 and 8.9 would be classified as moderately impaired, and sites with an MBI higher than 8.9 are considered impaired (IEPA, 2006).

IEPA data collected during 1996 and 2002 intensive basin surveys are presented in Table 3. The MMGWF data from the 2000 survey of impoundments are in Table 4. The calculated MBI was provided with both sets of data.

Figure 1 shows the MBI values displayed in spatial context. Low MBI values on the Fox River mainstem can be found predominantly at locations immediately below dams or at free-flowing locations.

**Table 3. IEPA Data for Fox River Mainstem**

<u>Stream</u>	<u>Site</u>	<u>Method</u>	<u>Year</u>	<u>MBI</u>	<u>FoxDB ID</u>
Fox River	DT-01 A	Hester-Dendy	2002	9.7	31
Fox River	DT-03	hand picking	2002	6.5	33
	DT-03 C	Hester-Dendy	2002	5.8	33
Fox River	DT-06	not specified	1996	7.6	24
	DT-06	hand picking	2002	6.8	24
	DT-06 B	Hester-Dendy	2002	8	24
Fox River	DT-09	not specified	1996	5.5	26
	DT-09	hand picking	2002	6.4	26
Fox River	DT-22	not specified	1996	8	23
	DT-22	hand picking	2002	9.4	23
	DT-22 B	Hester-Dendy	2002	8.9	23
Fox River	DT-35 A	Hester-Dendy	2002	7.7	197
Fox River	DT-36	hand picking	2002	8.8	37
Fox River	DT-38	hand picking	2002	6.5	27
	DT-38 A	Hester-Dendy	2002	9.6	27
Fox River	DT-69 C	Hester-Dendy	2002	9.7	40
Indian Creek	DTA-05	not specified	1996	5.9	91
Indian Creek	DTA-08	20-jab	2002	5.9	21
Little Indian Creek	DTAB-01	not specified	1996	7.1	41
Little Indian Creek	DTAB-02	not specified	1996	5	94
	DTAB-02	20-jab	2002	5.4	94
Big Rock Creek	DTC-07	not specified	1996	5.3	99
	DTC-07	20-jab	2002	5.5	99
Little Rock Creek	DTCA-01	20-jab	2002	4.7	51
Little Rock Creek	DTCA-04	not specified	1996	5.3	1046
Blackberry Creek	DTD-02	not specified	1996	4.7	28
	DTD-02	20-jab	2002	5.3	28
Ferson Creek	DTF-02	not specified	1996	5.3	14
	DTF-02	20-jab	2002	5.6	14
Poplar Creek	DTG-02	hand picking	2002	6	25
Nippersink Creek	DTK-04	not specified	1996	5	236
North Branch Nippersink Creek	DTKA-04	not specified	1996	4.7	2
Buck Creek	DTZB-02	not specified	1996	6.1	22
	DTZB-02	20-jab	2002	5.9	22
Tyler Creek	DTZP-04	not specified	1996	4.8	5
	DTZP-04	20-jab	2002	5.6	5
Flint Creek	DTZS-01	20-jab	2002	6.7	4
Flint Creek	DTZS-02	not specified	1996	5.9	1045
Boone Creek	DTZT-02	not specified	1996	4.6	3
	DTZT-02	20-jab	2002	5.4	3

**Table 4. MMGWF Data for Fox River Mainstem**

<u>Location</u>	<u>River mile</u>	<u>Method</u>	<u>Year</u>	<u>MBI</u>	<u>FoxDB ID</u>
Stratton above dam	98.2		2000	8.2	537
Stratton below dam	97.7		2000	8.2	535
Algonquin mid upper	93.9		2000	6.0	484
Algonquin mid lower	88.2		2000	6.2	259
Algonquin above dam	81.9		2000	7.6	486
Algonquin below dam	81.2		2000	5.8	482
Carpentersville above dam	77.5		2000	6.7	490
Carpentersville below dam	76.8		2000	5.4	488
Elgin mid upper	74.8		2000	6.4	499
Elgin mid lower	72.9		2000	7.9	500
Elgin above dam	71.3		2000	7.5	501
Elgin below dam	70.6		2000	7.5	497
South Elgin above dam	67.5		2000	7.0	525
South Elgin below dam	66.4		2000	6.9	523
St. Charles mid upper	64.0		2000	6.3	528
St. Charles mid lower	61.4		2000	6.7	529
St. Charles above dam	60.0		2000	7.5	530
St. Charles below dam	59.4		2000	7.2	527
Geneva above dam	58.0		2000	6.1	505
Geneva below dam	57.5		2000	5.7	503
North Batavia above dam	55.7		2000	8.0	518
North Batavia below dam	55.1		2000	5.9	517
South Batavia above dam	54.3		2000	8.1	90
South Batavia below dam	53.7		2000	5.5	520
North Aurora above dam	52.0		2000	7.9	515
North Aurora below dam	51.5		2000	5.8	517
Stolp Island above dam	48.6		2000	6.7	533
Stolp Island below dam	48.1		2000	6.6	532
Hurd's Island above dam	47.8		2000	7.0	508
Hurd's Island below dam	47.5		2000	5.6	506
Montgomery above dam	46.5		2000	6.6	511
Montgomery below dam	46.0		2000	6.0	509
Yorkville mid upper	42.3		2000	5.7	33
Yorkville mid lower	38.6		2000	5.5	541
Yorkville above dam	36.3		2000	7.0	542
Yorkville below dam	35.6		2000	6.2	538
Dayton mid upper	25.0		2000	5.6	70
Dayton mid lower	14.2		2000	6.2	494
Dayton above dam	5.8		2000	8.0	495
Dayton below dam	5.3		2000	6.6	492

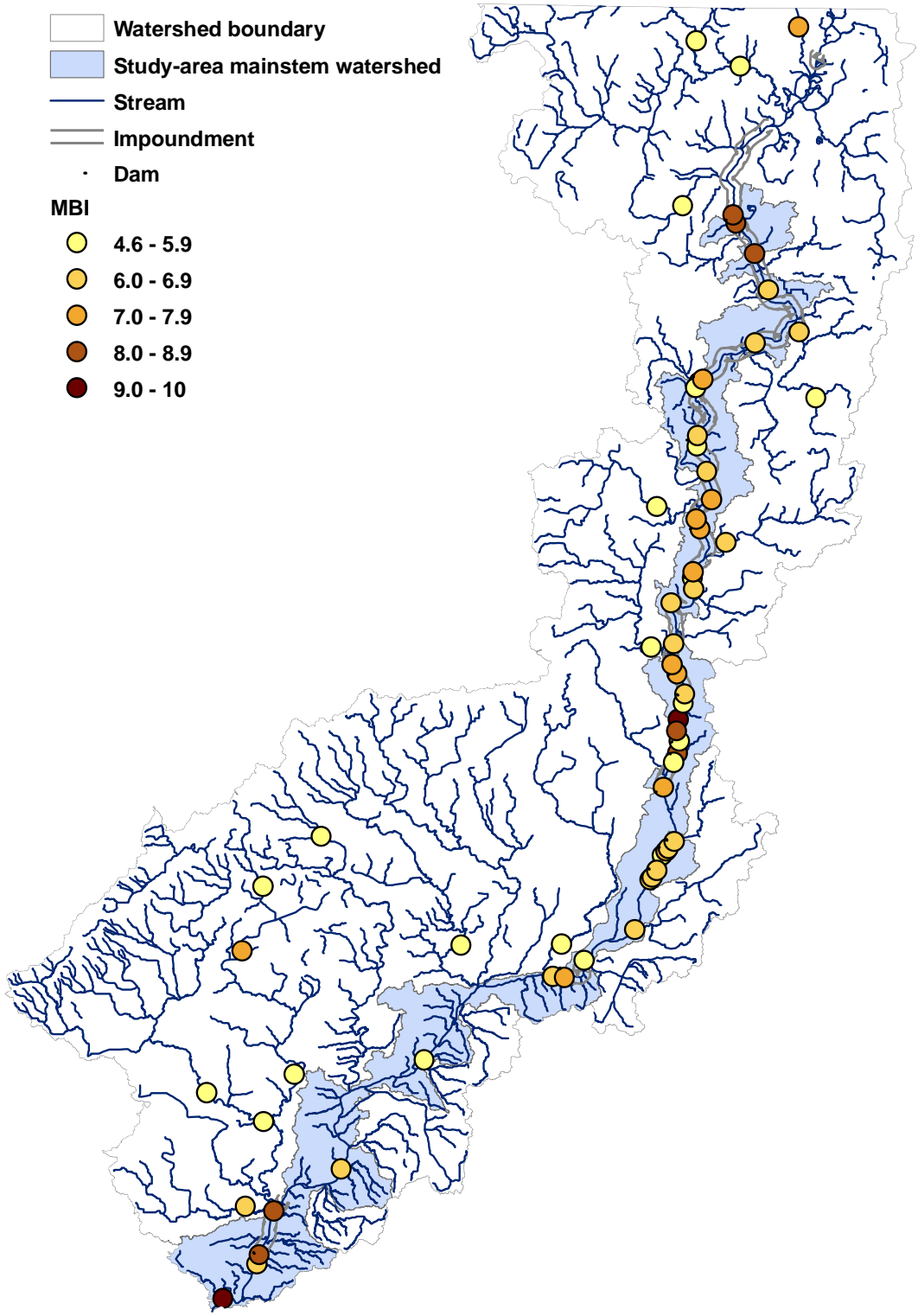


Figure 1. Spatial distribution of MBI in the Fox River watershed (1996-2002 data)

The Fox River mainstem generally showed higher values (5.4-9.7 with an average of 7.0) than its tributaries (4.7-7.1 with an average of 5.5). There is a statistical difference<sup>1</sup> between medians as well as standard deviations of MBIs in the two groups. Figure 2a shows a Box-and-Whisker plot of the two groups.

The Box-and-Whisker plot divides the data for each category into four areas of equal frequency, with a box enclosing the middle 50%, i.e., from 25<sup>th</sup> percentile to 75<sup>th</sup> percentile. The median is drawn as a vertical line inside the box. Horizontal lines, known as whiskers, extend from each end of the box. The lower whisker is drawn from the 25<sup>th</sup> percentile to the smallest point within 1.5 interquartile ranges from the lower quartile. The other whisker is drawn from the upper quartile to the largest point within 1.5 interquartile ranges from the upper quartile; values that fall beyond the whiskers but within 3 interquartile ranges are plotted as individual points. Those values are suspect outliers. The far outside outliers, those points more than 3 interquartile ranges below the lower quartile or above the upper quartile, are plotted using a special character (a point with a plus (+) through it) so they are easy to distinguish.

Data available for the Fox River mainstem were categorized as free-flow or impounded based on the flow regime at a sampling site. Impounded sites typically have higher MBI values (6.0-9.7 with an average of 7.6) than free-flowing sites (5.4-9.7 with an average of 6.5), i.e., the free-flowing sites have healthier macroinvertebrate communities (Figure 2b).

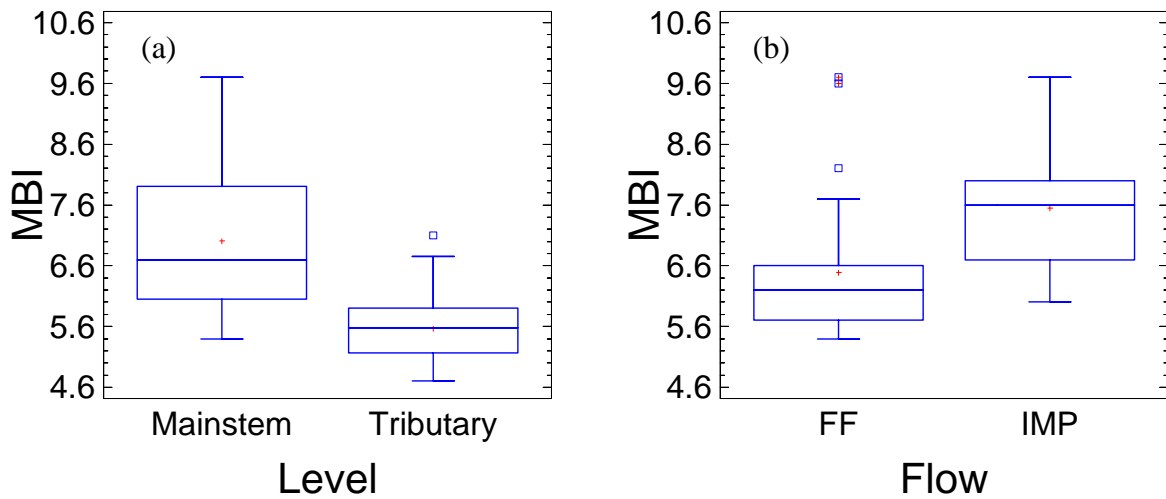
The effects of impoundment were thoroughly investigated by the MMGWF study (Santucci and Gephard, 2003). Free-flowing reaches supported higher quality macroinvertebrate communities, including higher abundance and richness of mayflies and caddis flies, than impounded waters above dams. Sites immediately below dams typically had higher densities of some taxa due to nutrient enrichment and high plankton production in impoundments. Tolerant chironomid larvae and aquatic worms dominated open-water areas of impoundments.

The watershed was divided into two parts to evaluate the change in MBI with geographic location. The break-point at the confluence of Fox River and Waubensee Creek separates the rural areas of the lower Fox River watershed from more urbanized areas upstream. The distribution of values does not show a statistically significant difference between MBI values in the upper or lower part of the watershed, both for mainstem and tributary locations (Figure 3a,b). Identification of any difference is probably hindered by the strong impact of the impoundments.

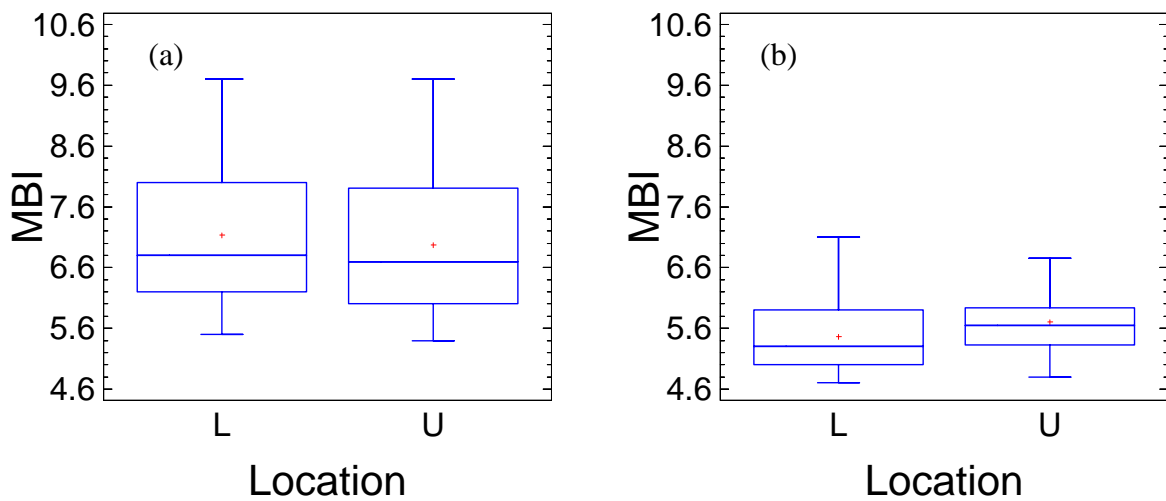
The upper part of the watershed has a disproportionately larger number of sampling points, so further division into smaller sections was investigated. However, even dividing the upper part into four smaller sections with division points at Algonquin Dam, Norton Creek, and Mill Creek did not lead to statistically significant differences in subsamples.

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<sup>1</sup> Statistical significance  $\alpha=0.05$  is used throughout this report.



**Figure 2. Comparison of MBI in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem**



**Figure 3. Comparison of MBI in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries**

## Fish

Fish communities are evaluated using an Index of Biological Integrity, or IBI (Karr et al., 1986; Karr, 1991). The IBI is calculated using several metrics that include parameters related to species richness and composition, trophic composition, and organism abundance and condition. Ten metrics are used in the revised Illinois IBI, six of which are based on richness, three on trophic or reproductive structure, and one on tolerance. Metric values are scaled according to geographic region, stream size, and slope; scores for the revised IBI can range from 0 to 60 (Smogor et al., 2008). High scores reflect high fish biotic integrity. The IEPA uses a threshold of 41 to identify streams with no impairment; sites with an IBI between 20 and 41 would be classified as moderately impaired, and sites with an IBI lower than 20 are impaired (IEPA, 2006).

The IEPA and the USGS data include 84 and 38 fish-sampling events at 32 and 38 locations within the study area, respectively, during years 1990 to 2002. The results of the 2007 Intensive Sampling Program were not available at the time of these analyses. The MMGWF sampled 40 stations on the mainstem during the summer of 2000. Together, the sampling represents data from 162 sampling events conducted at 103 individual sampling locations. Note that these numbers are smaller than the sum of individual events and locations as five sampling events were present in both IEPA and USGS programs and seven locations were sampled by more than one organization. Only the latest sampling event from each site was used to avoid biasing the analysis towards sampling sites with a large number of samples. Most sampling events used in the analysis (90%) occurred in 1997 and after.

Selected metrics often used in IBI determination are summarized in Table 5. Not all of these directly coincide with the revised Illinois IBI as the reference tables in FoxDB describing and categorizing individual species were originally created for data sources across several states and ecoregions. The reference tables will be updated with information needed to calculate all Illinois IBI metrics once the IEPA supporting documents are finalized. Given the pending revisions, the IBI was not calculated, but the variation of the different metrics is presented.

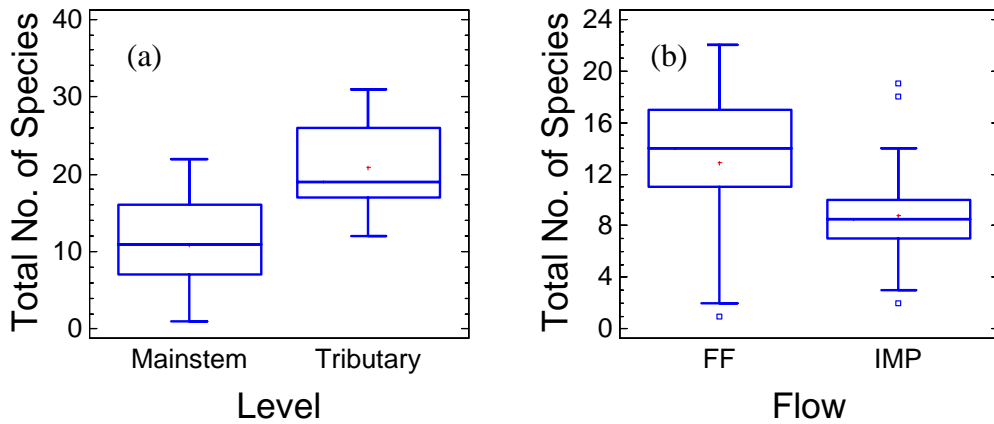
The total number of fish caught during the sampling event serves as a relative comparison of fish abundance between sampling sites. Severely impaired sites showed a depleted number of fish. Several metrics evaluate the number of species present, or species richness. Impaired streams typically support less species than healthy, unimpaired streams. A decrease in specialized invertebrate feeders accompanied by an increase in generalists often indicates poor conditions associated with water quality and/or physical habitat degradation. A lower number of insectivorous cyprinids may also indicate an increase in toxicity.

A lower number of fish caught, less species present, and less specialized feeders were typically found in the Fox River mainstem impounded sites of the upper part of the watershed. All these characteristics indicate higher impairment than sampling sites located on tributaries, free flowing sites, or sites in the lower part of the watershed.

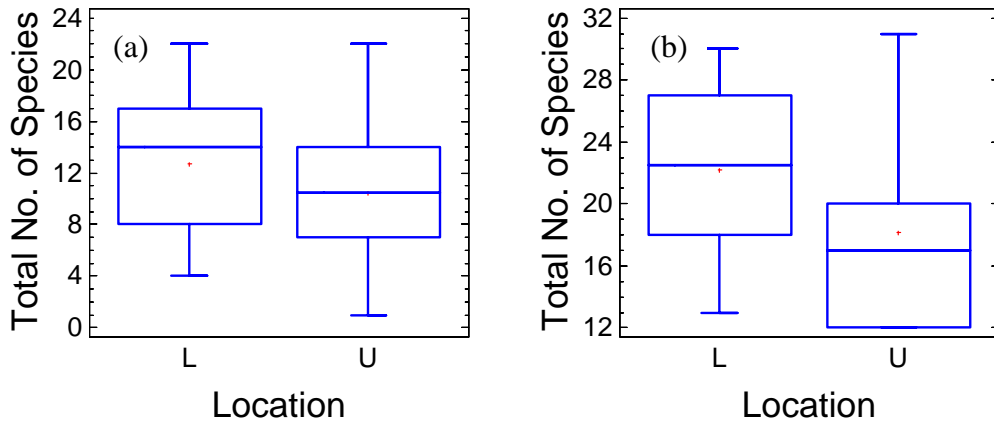
**Table 5. Average Values of Selected Fish Metrics**

<i>Metric</i>	<i>Level</i>		<i>Flow regime</i>		<i>Location</i>		<i>Total</i>
	<i>Mainstem</i>	<i>Tributary</i>	<i>Free-flow</i>	<i>Impounded</i>	<i>Lower Fox</i>	<i>Upper Fox</i>	
Total catch	118.9	698.3	581.1	187.3	393.2	88.8	298.7
Total No. species	8.8	20.2	18.7	9.8	15.0	6.3	12.3
No. sucker species	1.7	2.9	3.8	1.5	2.8	0.7	2.1
No. sunfish species	1.4	2.0	2.0	1.5	1.7	1.4	1.6
No. minnow species	0.9	8.3	6.5	2.0	4.4	0.7	3.2
Percent top carnivores	56.7	3.4	14.8	50.1	31.8	58.7	40.1
Percent hybrids	0.7	0.1	0.3	0.5	0.2	1.2	0.5
Percent omnivores	18.7	22.7	19.8	20.3	24.8	18.0	19.9
Percent insectivorous cyprinids	3.6	67.1	32.2	3.6	46.4	14.2	23.3
Percent lithophiles	10.9	23.9	24.2	11.3	19.6	4.7	15.0

Metrics with significant variation were evaluated using the same categorization of sampling locations as in the previous section. Maps showing spatial distribution of selected metrics are presented in Appendix A. The total number of species (species richness) is higher in tributary sites, followed by free-flowing sites of the mainstem and impounded sites of the mainstem (Figure 4). The difference in sites of the upper and lower parts of the watershed is not statistically significant ( $\alpha = 0.05$ ) for mainstem nor tributaries (Figure 5).



**Figure 4. Total number of species in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem**



**Figure 5. Total number of species in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries**

The number of minnow species was significantly higher in tributaries than in mainstem sites (Figure 6). There is no statistical difference between free-flowing and impounded sites, or between upper and lower watershed sites of the mainstem for this metric (Figure 6b and Figure 7a). However, tributaries in upper watershed sites typically have a higher number of minnow species.

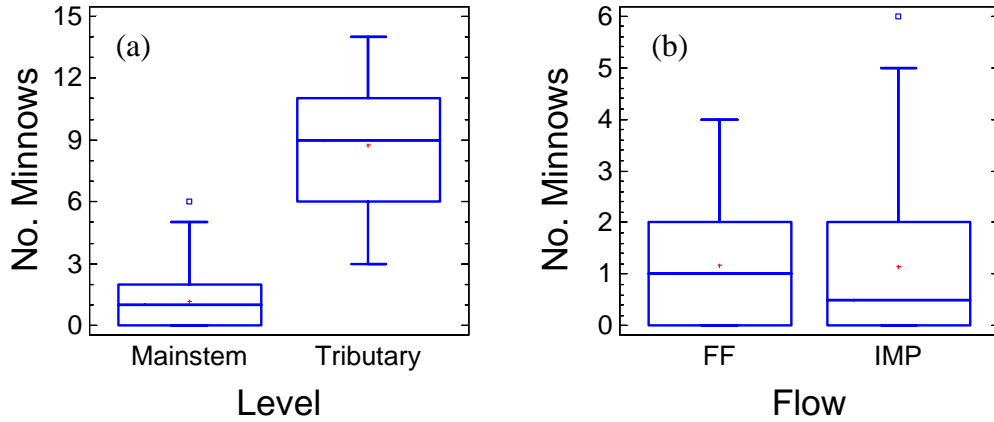


Figure 6. Number of minnow species in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem

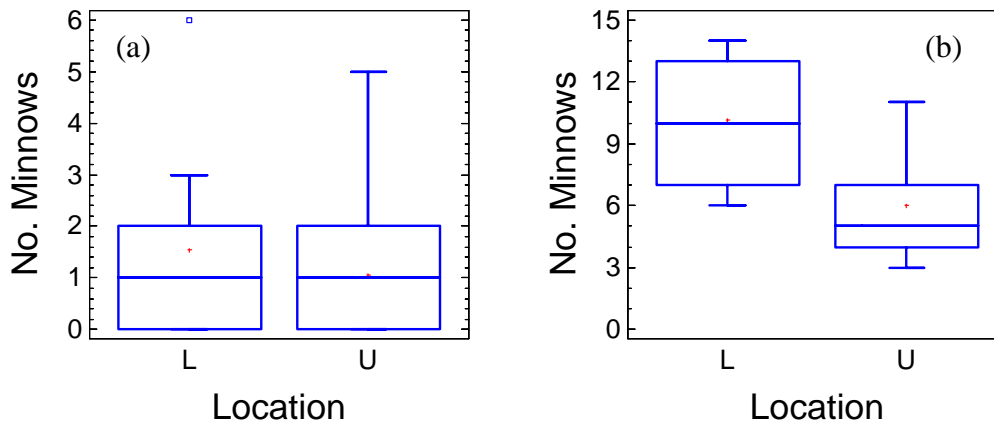


Figure 7. Number of minnow species in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries

Streams with slight or moderate water quality impairment generally contain several top predator fish species. The proportion of top carnivores was higher at the mainstem sites, though there was no difference between free-flowing and impounded sites of the mainstem (Figure 8). The difference between upper and lower watershed sites is not statistically significant (Figure 9).

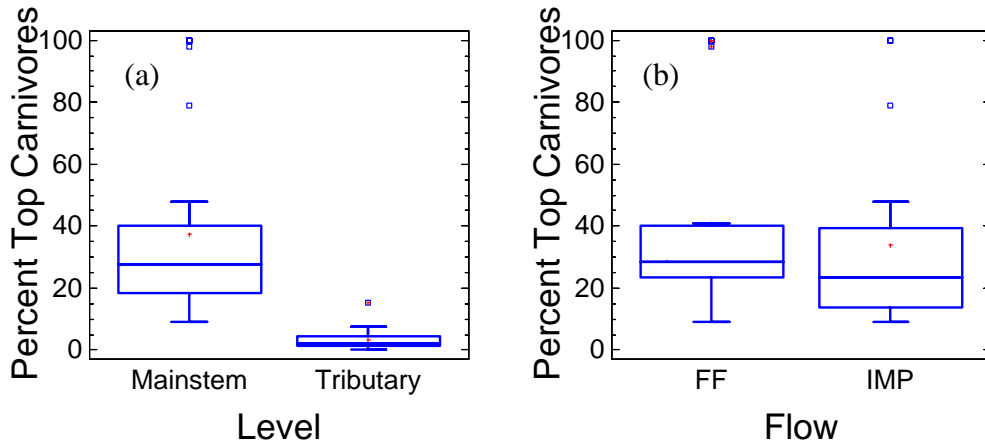


Figure 8. Proportion of top carnivores in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem

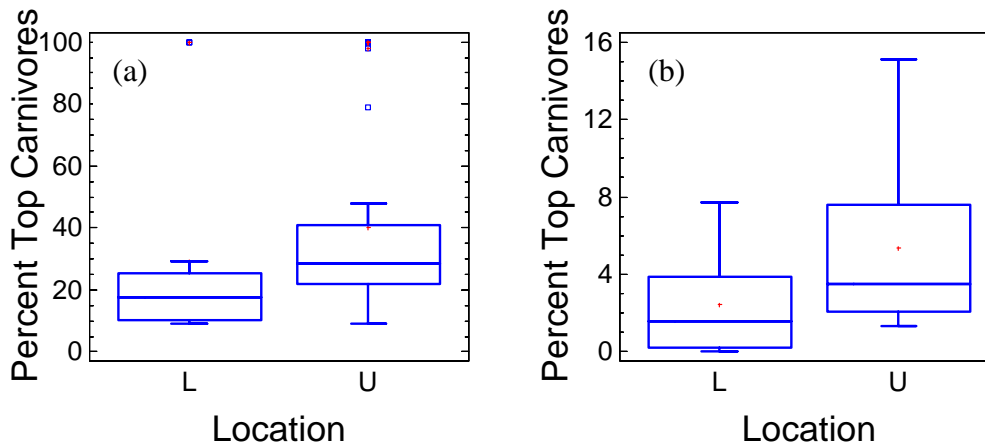


Figure 9. Proportion of top carnivores in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries

Although the difference in proportion of hybrids in tributary and mainstem sites as well as in free-flowing and impounded sites of the mainstem is not statistically significant, values higher than 5% are found only in the mainstem (Figure 10). These high proportions are mostly in impounded sites with one exception found in a free-flowing site (Station ID = 527). This station (located 0.5 km below St. Charles Dam) was sampled by the MMGWF in August 2000. Similarly, the difference between the upper and lower mainstem sites is not statistically significant, though proportions over 5% are mostly found in the upper part of the watershed, which is where most of the impounded sites are located. Upper watershed sites located on tributaries show a higher proportion of hybrids, though all values are below 0.5% (Figure 11).

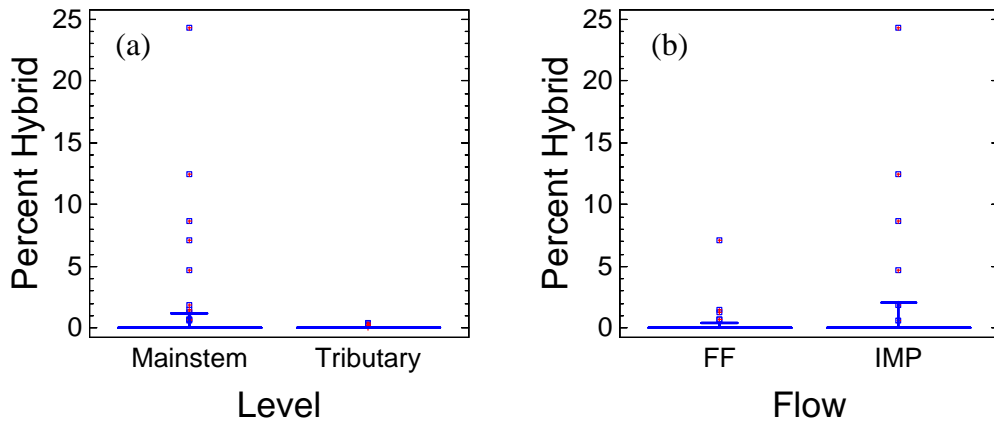


Figure 10. Proportion of hybrids in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem

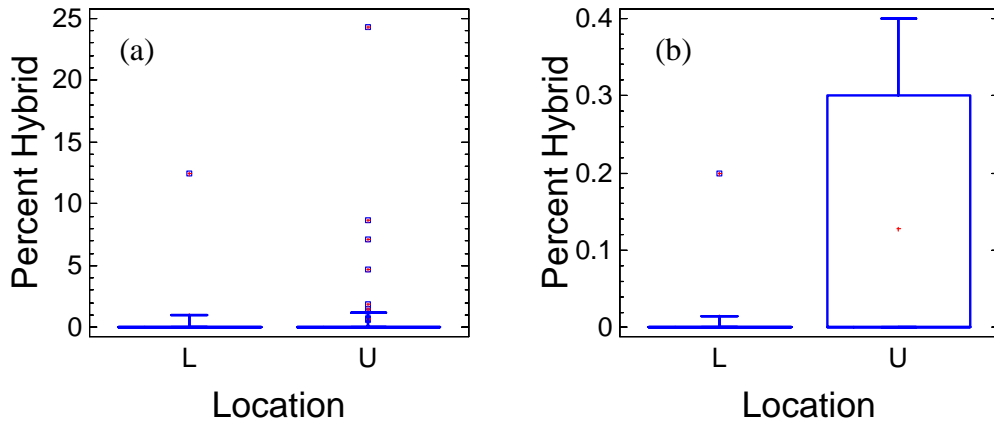
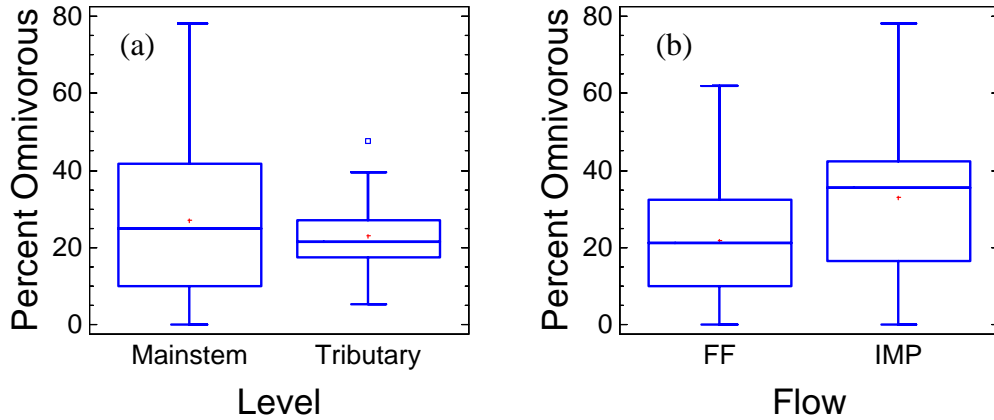
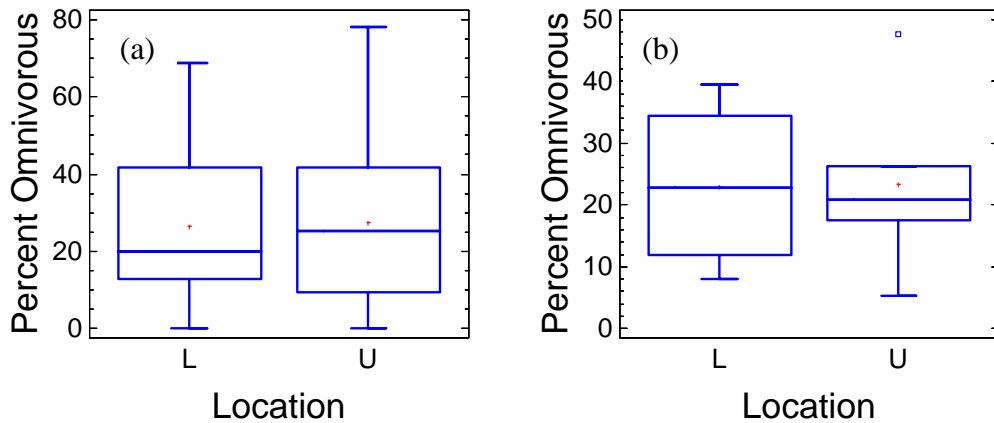


Figure 11. Proportion of hybrids in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries

Often a shift from specialist groups to generalist or omnivorous groups occurs as water quality becomes degraded. The proportion of omnivores is higher in the impounded sites of the mainstem. The difference between mainstem and tributary sites is not statistically significant, though mainstem sites show a higher standard deviation than tributary sites (Figure 12). There is no statistical difference between sites in the upper and lower parts of the watershed (Figure 13).

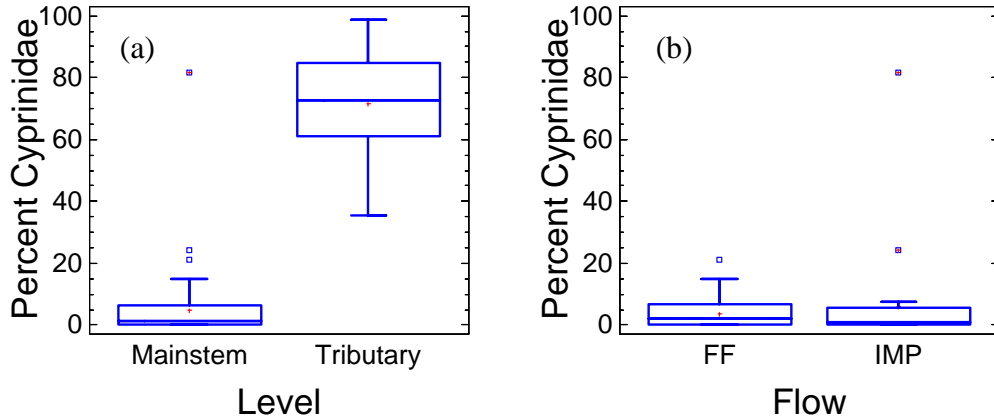


**Figure 12. Proportion of omnivores in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem**

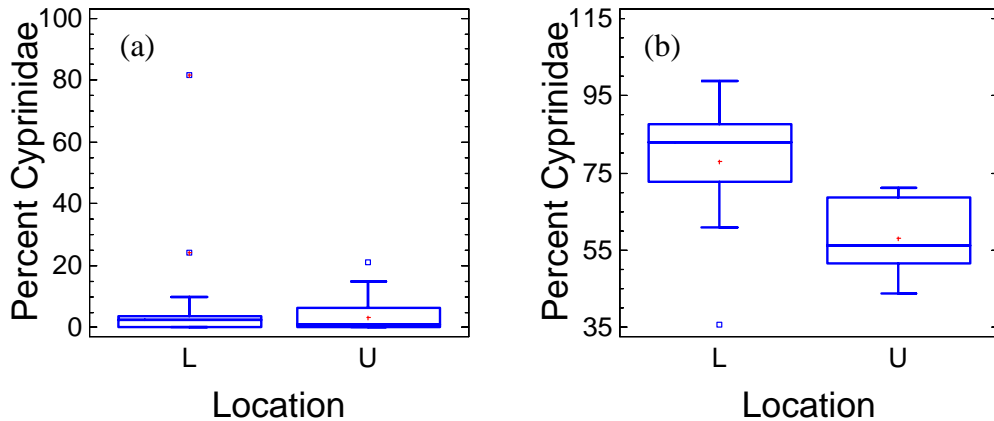


**Figure 13. Proportion of omnivores in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries**

The difference in the proportion of insectivorous cyprinids in mainstem and tributary sites is very notable (Figure 14). Cyprinids in tributary sites comprise 70% of all fish caught on average (minimum is 35%). Mainstem sites average 4% of cyprinids in the catch. Tributaries in the lower part of the watershed show a higher proportion of cyprinids than tributaries in the upper part of the watershed, though there is no statistical difference between upper and lower mainstem sites (Figure 15).

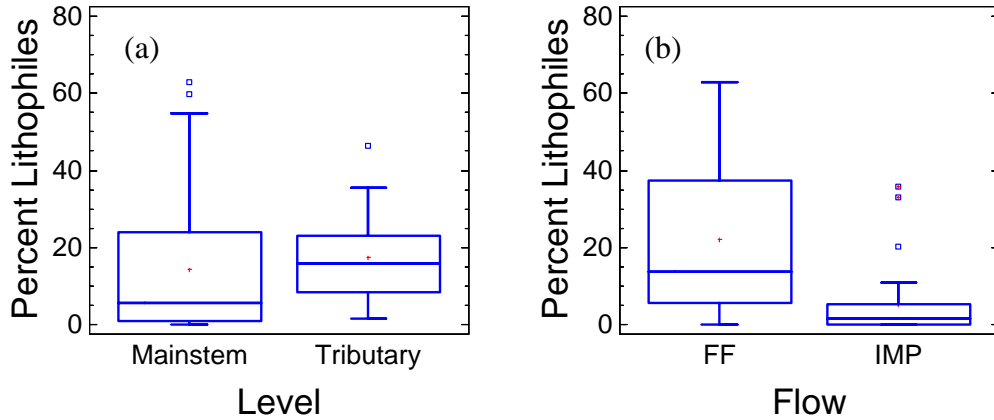


**Figure 14. Proportion of insectivorous cyprinids in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem**

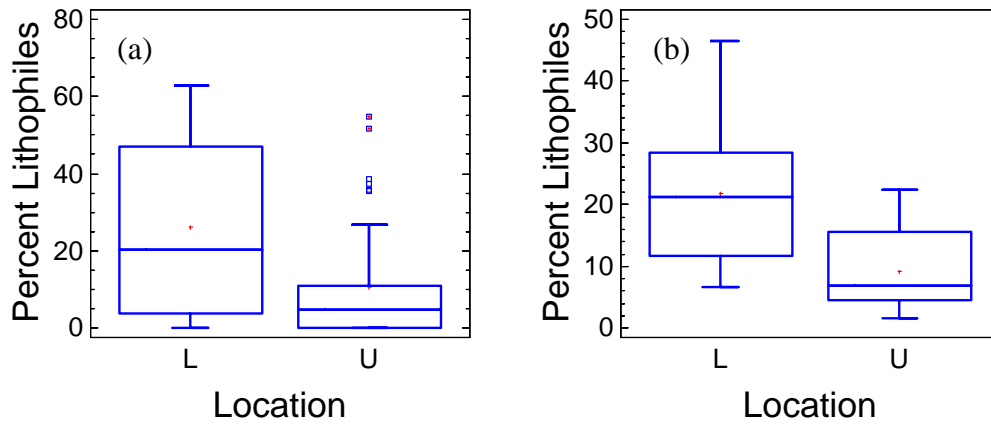


**Figure 15. Proportion of insectivorous cyprinids in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries**

The proportion of lithophilic spawners in the free-flowing mainstem sites is higher than in the impounded mainstem sites, though there is no statistically significant difference between mainstem and tributary sites due to averaging over different flow regimes (Figure 16). Sites in the lower part of the watershed typically show a higher proportion of lithophiles than sites in the upper part of the watershed (Figure 17).



**Figure 16. Proportion of lithophiles in (a) Fox River mainstem and its tributaries, and (b) free-flowing (FF) and impounded (IMP) reaches of Fox River mainstem**



**Figure 17. Proportion of lithophiles in lower (L) and upper (U) Fox River (a) mainstem and (b) tributaries**

## Relations to Habitat

### Habitat Measures

An evaluation of habitat quality is critical to any assessment of ecological integrity. Habitat is a principal determinant of biological potential and can be used as a general predictor of biological condition. Biological potential is often limited by the quality of the habitat structure. Habitat assessment is becoming an inseparable part of water resources management.

Habitat data are typically collected at the same time as biological data. Habitat quality is often evaluated by characterizing selected physicochemical parameters and then comparing them to the habitat quality of a reference stream. Various protocols have been used to evaluate stream habitat and its suitability to sustain aquatic life (Rankin, 1995). The IEPA collects both quantitative and qualitative variables (IEPA, 1995). The quantitative variables collected during intensive basin surveys using transect assessment procedure include substrate composition, mean depth, velocity, width, percentages of pools and riffles, shading, and instream cover. A total score of 15 metrics forms the basis of overall habitat quality for the reach as specified in the Stream Habitat Assessment Procedure, or SHAP. However, SHAP represents a qualitative assessment rather than a physical measurement as each metric is subjectively assessed and assigned a score (Table 6). SHAP metrics include bottom substrate, pool substrate, channel alteration, mean depth, bank stability, shading, and instream cover. SHAP is used to evaluate stream habitat conditions yielding scores ranging from 208 (best) to 15 (worst).

**Table 6. SHAP Metrics**

<i>METRIC</i>	<i>Excellent</i>	<i>Good</i>	<i>Fair</i>	<i>Poor</i>
<i>Substrate and instream cover</i>				
Bottom substrate	16-20	11-15	6-10	1-5
Deposition	10-12	7-9	4-6	1-3
Substrate stability	13-16	9-12	5-8	1-4
Instream cover	10-12	7-9	4-6	1-3
Pool substrate	16-20	11-15	6-10	1-5
<i>Channel morphology and hydrology</i>				
Pool quality	13-16	9-12	5-8	1-4
Pool variability	13-16	9-12	5-8	1-4
Channel alteration	7-8	5-6	3-4	1-2
Channel sinuosity	10-12	7-9	4-6	1-3
Width/depth	13-16	9-12	5-8	1-4
Hydrolic diversity	10-12	7-9	4-6	1-3
<i>Riparian and bank features</i>				
Canopy cover	10-12	7-9	4-6	1-3
Bank vegetation	13-16	9-12	5-8	1-4
Immediate land use	7-8	5-6	3-4	1-2
Flow-related refugia	10-12	7-9	4-6	1-3

The MMGWF followed SHAP and Qualitative Habitat Evaluation Index (QHEI) protocols in collecting habitat data. QHEI, developed and used by the Ohio EPA (Rankin, 1989), evaluates and assigns a score to substrate composition, instream cover, channel morphology, bank and riparian zone, pools and riffles, and reach gradient. Scores for each category were originally assigned based on a literature review of the response of warm-water fish species and communities to various habitat characteristics. The original scores were adjusted by examining the response of the IBI at reference sites to each of the QHEI habitat characteristics. Streamflow data are not an explicit part of the QHEI. Habitat attributes are visually estimated over a 150 to 500 meter reach that corresponds to a biological sampling reach. Physical habitat attributes are evaluated within the following categories:

- substrate                      most predominant substrate type, number of substrate types, substrate origin, embeddedness, silt cover (best score = 20)
- instream cover                presence and extensiveness of different types (best score = 20)
- channel morphology        channel sinuosity, degree of pool/riffle development, channel modifications, stability (best score = 20)
- riparian quality              width of riparian vegetation, adjacent land use, extensiveness of bank erosion (best score = 10)
- pool/riffle quality          average and maximum depth, morphology, presence of current types, stability and embeddedness of substrate (best score = 20)
- map gradient                 calculation of elevation drop through sampling area; accounts for varying influence of gradient with respect to stream size (best score = 10)

The major difference between the QHEI and SHAP habitat evaluation is not the types of variables, although specific variables do differ, but rather in the weighing of these factors as to their influence on biological integrity.

### **Habitat Analysis: Fox River Mainstem**

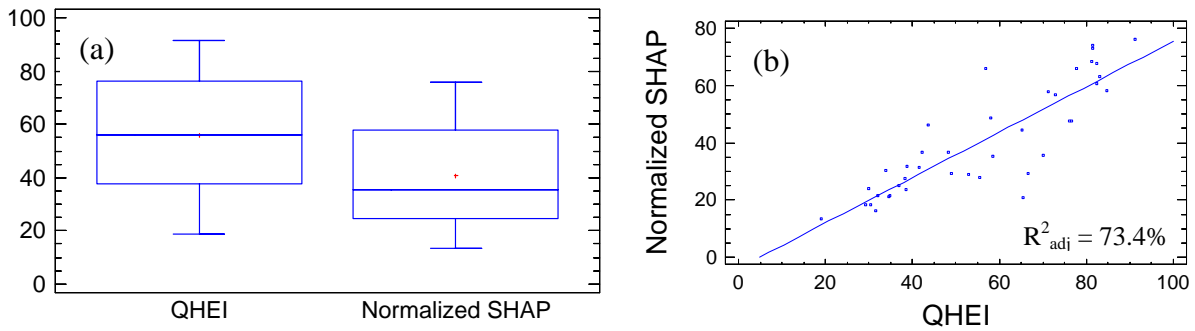
FoxDB contains 126 sites with at least limited information on habitat or stream characteristics, 81 of which were evaluated in detail using a habitat assessment protocol. Habitat data were provided by the IEPA and the MMGWF. Data received from the IEPA do not contain QHEI and SHAP scores, however, only physical measurements. The QHEI and SHAP scores are valuable as they provide an overall evaluation of available habitat.

Results of QHEI and SHAP scores available for 40 sites on the mainstem are summarized in Table 7. Since the range of possible values is different for each index, SHAP was normalized to a maximum allowable score of 100 to simplify comparison. There is a statistically significant difference between QHEI and normalized SHAP scores (Figure 18a) that may be a direct result of different weights assigned to habitat parameters in these protocols. As there is a strong correlation between the two scores (Figure 18b), the QHEI score is analyzed for the effects of habitat and location. Impounded sites of the Fox River mainstem receive a lower score, indicating habitat degradation associated with dams (Figure 19a and Figure 20). The difference between upper and lower mainstem sites is not statistically significant. However, only 7 of 40 sites are located in the lower part of the watershed (Figure 20).

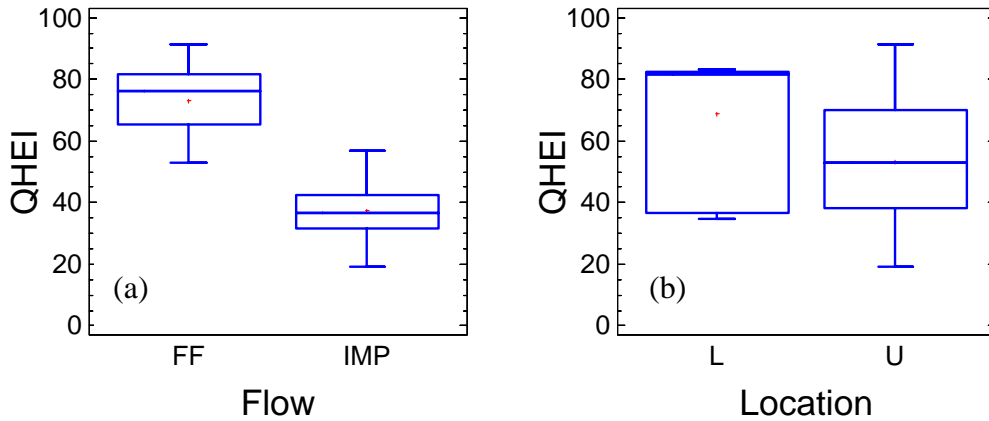
**Table 7. QHEI and SHAP Scores on the Fox River Mainstem**

<i>Statistic</i>	<i>QHEI</i>	<i>SHAP</i>	
Maximum value possible (perfect habitat)	100	208	100*
Average	56.1	84.5	40.6*
Median	56.2	73.5	35.3*
Minimum	19	28	13*
Maximum	91	158	76*
Standard deviation	20.5	39.2	18.9*

**Note:** \* values normalized to maximum of 100



**Figure 18. Comparison of QHEI and normalized SHAP (a) distribution, and (b) correlation (Normalized SHAP =  $-3.79 + 0.792 \cdot \text{QHEI}$ )**



**Figure 19. QHEI score in (a) free-flowing (FF) and impounded (IMP) reaches, and (b) lower (L) and upper (U) part of Fox River mainstem**

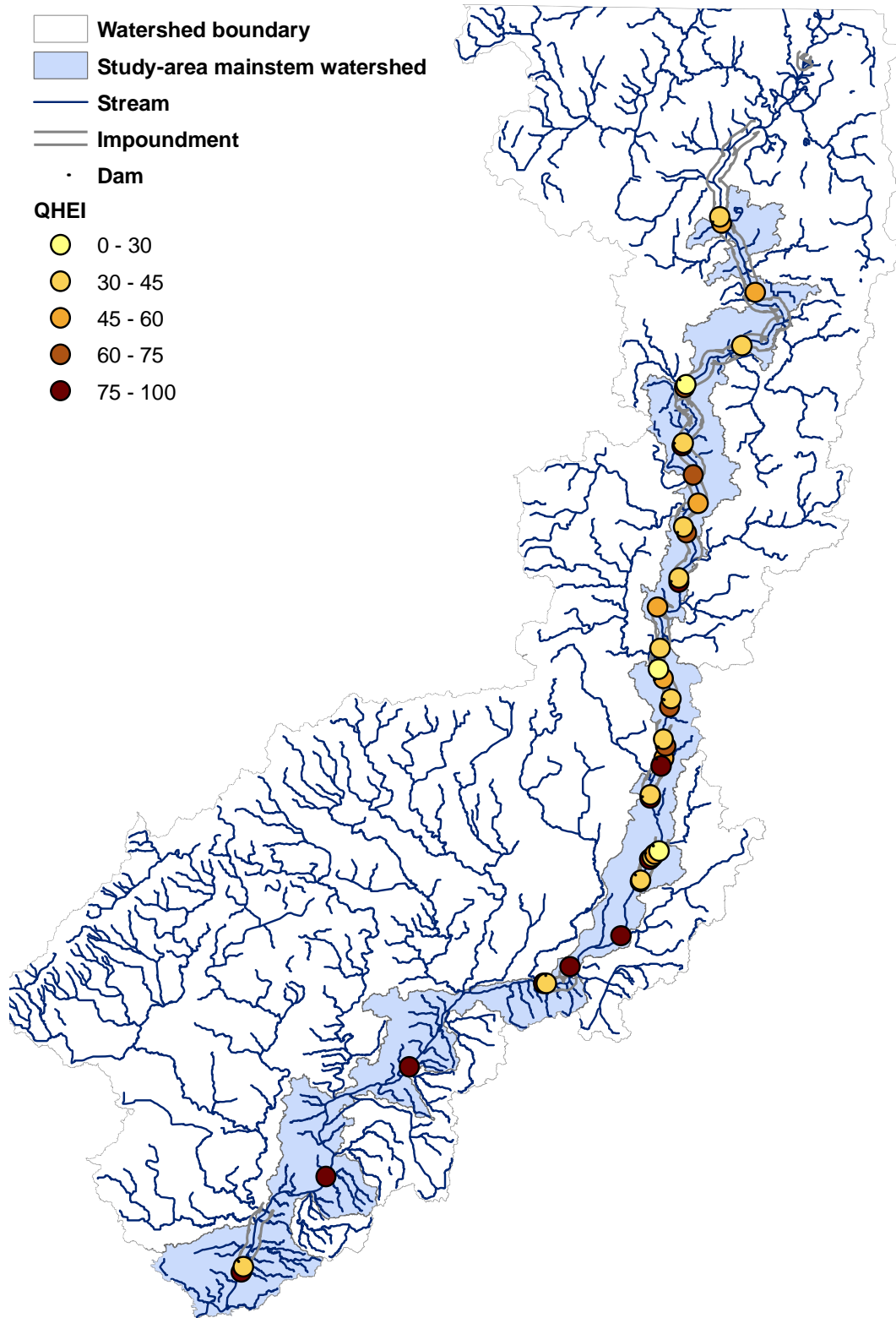
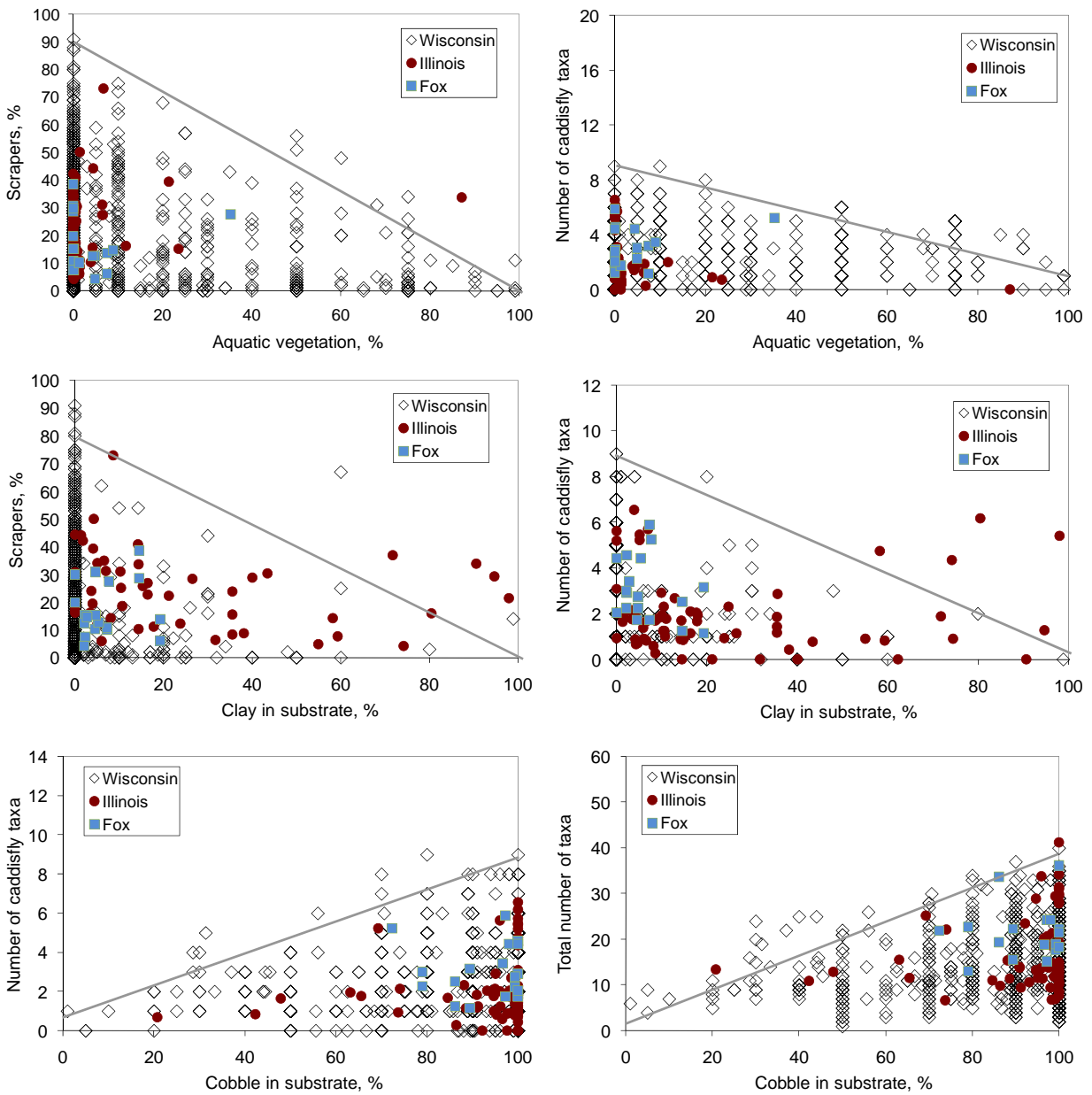


Figure 20. Spatial distribution of QHEI scores, Fox River mainstem

## Summary of STAR Watershed Research

Biological and habitat data collected in northern Illinois (including the Fox River watershed) by the IEPA and IDNR were analyzed in a separate study conducted under Grant No. R83-0885-010 to Northeastern University from the USEPA/NSF/USDA STAR Watershed Program (Bartosova, 2008; Novotny, 2007). The relationship of community metrics to habitat was investigated and ecological risk to aquatic biota was estimated for individual stressors using a probabilistic approach. Exposure response curves for habitat characteristics were developed by Bartosova (2002) using biological and habitat data collected by the Wisconsin Department of Natural Resources (WDNR). Since WDNR and IEPA use different sampling protocols, taxa abundance was normalized assuming a constant number of individuals per catch (100). Figure 21 shows modified community metrics for two datasets, original WDNR data and the IEPA data for northern Illinois with Fox River watershed data displayed as a special category. The data mostly follow a similar pattern, regardless of the source, though the actual range of values may differ.

The variability in biotic metrics and indexes was quantified through multiple regression analysis using directly measured environmental variables as well as indirect probability-based risks (Table 8 and Table 9). In all cases, less than 55% variability in biological endpoints was explained by habitat and water quality or risk variables. Although much of this variability remained unexplained, all relationships were statistically significant and stronger than typically reported in the literature. Inclusion of habitat characteristics, such as percentages of canopy cover, brush debris jams, terrestrial vegetation, and rock ledge, in calculating risk variables was recommended to further improve multiple regression equations and to increase their explanatory power (Bartosova, 2008).



**Figure 21. Relationship between community metrics and habitat (modified from Bartosova, 2008)**

**Table 8. Direct Effect of Environment on Biotic Indexes: Results of Multiple Regression Analysis (Bartosova, 2008)**

<u>Statistics</u>	<u>MBI</u>	<u>ICI</u>
F limit	4	3
R <sup>2</sup> <sub>adj</sub>	53.0%	52.8%
Standard error	0.41	5.43
Maximum p-value	0.03	0.06
Regression equation	5.30	24.9
	+ 0.0420 (Cu in sediment)	- 0.278 (Cu in sediment)
	+ 0.00991 (Zn)	
	- 0.846 x log10 (stream width)	+ 22.5 x log10(stream width)
		- 8.74 x log10(watershed size)
	- 0.0163 (% medium gravel)	+ 0.287 (% medium gravel)
	+ 0.00581 (% silt mud)	+ 0.975 (% rock ledge)
	+ 0.0166 (% clay)	- 4.36 (% brush debris jam)
	- 0.00997 (% canopy cover)	- 0.164 (% submerged terrestrial vegetation)

Note: Cu is copper and Zn is zinc.

**Table 9. Indirect Effect of Environment on Biotic Indexes: Results of Multiple Regression Analysis (Bartosova, 2008)**

<u>Statistics</u>	<u>MBI</u>	<u>ICI</u>
F limit	4	4
R <sup>2</sup> <sub>adj</sub>	25.3%	31.9%
Standard error	0.51	6.5
Maximum p-value	0.001	0.03
Regression equation	5.68	37.0
	- 1.04 (risk to filterers due to clay)	+ 7.55 (risk to filterers due to clay)
	+ 2008 (sediment toxicity)	+ 5240 (acute water toxicity)
		- 38200 (sediment toxicity)



## Update to FoxDB Structure

The relational FoxDB was originally developed to compile water and sediment quality data collected in the Fox River watershed and obtained from multiple sources (McConkey et al., 2004). It contains all available water and sediment quality data collected in the Fox River and its tributaries since the 1970s. The FoxDB structure was further modified and expanded to include raw biological (taxonomic) data and habitat information, incorporating changes made when developing a comprehensive database, Science-To-Achieve-Results (STAR) Environmental Database, or STARED (Bartosova et al., 2005). STARED was developed by the ISWS to store various environmental data, including water quality, sediment chemistry, biological indices, stream hydrology, and habitat for the purpose of another project funded by the U.S. Environmental Protection Agency STAR program. The database was based on the FoxDB structure, modified, and populated with biological and habitat data from other watersheds in northeastern Illinois, Maryland, Massachusetts, Minnesota, Ohio, and Wisconsin. An overview of the original structure of the FoxDB as well as a detailed description of its changes is described in the following section.

### Overview of Original FoxDB Structure

Figure 22 demonstrates the original structure of the FoxDB. Colored blocks group tables with a common theme such as sampling stations, samples taken at these sites, monitoring projects, parameters analyzed, and analysis results (counterclockwise direction from bottom right corner). Tables are related through arrows based on unique identifiers. Each table within a block then provides attributes describing the theme or providing reference information. For example, table *TBLSample* describing a sample collected by a crew at a sampling station includes a sample number uniquely identifying the sample, sampling date and time, sampling depth, medium, sampling stations, monitoring project, and so forth. Other tables explain codes used to describe the characteristics (e.g., sampled medium codes “W” as water, “S” as sediment, or “M” as macroinvertebrate taxa). Codes referring to projects are fully described in a separate table, *TBLProjects\_Programs*.

Database maintenance and data import are conducted with the help of the *IDLocations* code, which refers to the original file acquired from the particular data source. The *TBLIDLocations* table is not included in any of the above blocks, and is shown separately in the data model.

In the *Sample Related* block, the *TBLSample* table describes a sample, including information on the sampling station, sampling date and time, sampling depth, and the monitoring project under which it was collected. *TBLSample* is connected to three lookup tables. *TBLMedium* indicates what was sampled (water, sediment, biota, habitat characteristics). *TBLSample\_Type* describes sampling methods (transect composite, grab sample, continuous datasonde, fish taxa, etc.). *TBLComposite\_statistic\_code* indicates whether the measured value is an individual value or an average value (based on the USEPA STORage and RETrieval, or STORET database).



A station is defined in the *TBLStation\_Information* table with a unique identifier, “Station ID,” and several descriptive fields. Latitude, longitude, and standard identifiers such as the National Hydrography Dataset (NHD) Code and Reach File Version 3 (RF3) Code provide the means to display stations in the GIS environment and to relate them to national datasets. “Station\_Type” identifies whether the station is located on a stream, a lake, in a wetland, etc. Codes are explained in a lookup table, *TBLStation\_Type*. Additional columns and lookup tables include a description of the site, water body name, EPA or USGS station codes (if relevant), latitude and longitude accuracy level, and contributing area (when available from the original source). Watershed and reach level information derived using GIS can be found in tables related through “Station ID.” A separate table stores flow measurements, currently for selected USGS stations only.

The *Project Related* block is centered on the *TBLProjects\_Programs* table, linked to three other tables. *TBLProjects\_Programs* contains the records of monitoring project names with descriptions of study areas, project objectives and dates, codes for the monitoring organization, and contact information. *TBLOrganization* consists of full and abbreviated names and category of the organization, including its postal and Web site addresses. *TBLZip* simplifies recording of the organization postal address.

Parameter codes are adopted from Legacy STORET. Although the USEPA is phasing out the use of these six-digit codes, most available data are still referenced this way. The *TBLParameter\_Codes* table in the block *Parameter Related* closely follows the parameter table from Legacy STORET with a full and abbreviated description of parameters, reporting unit, and accuracy. Lookup information is provided in the following tables: *TBLReporting\_Units*, *TBLGroup\_Code*, *TBLMedia\_Group*, *TBLParameter\_Group*, *TBLGroup\_Codes*, and *TBLQAPP\_Groups*.

For grouping parameters, two schemes, the Legacy STORET scheme and the Quality Assurance Project Plan (QAPP) scheme, are used in this database. The QAPP scheme was developed by the ISWS (McConkey et al., 2004) together with the QAPP grading system to evaluate data quality. The QAPP three-digit coding scheme groups parameters on two levels, by sampled medium, and by constituent analyzed, and enables identification of the medium, the main parameter group, and the constituent subgroup. The main parameter group includes basic inorganics, nutrients, metals, and organics; the constituent subgroup comprises the number of groups such as nitrogen in the nutrients group or pesticides in the organics group.

Results described in the *Results Block* define actual values of parameters analyzed in a sample. Numerical and non-numerical results are stored in separate tables, *TBLResults* and *TBLResults\_Vol\_NonNumeric*, respectively. The third table, *TBLReplicates*, is used to store all replicate results. The structure of these tables is very similar. For each sample identified by a unique ID, the result is the concentration value for a parameter specified by the parameter code. A remark code may accompany a result with additional information about quality issues such as “below the detection limits” or “calculated value.” Unreliable or questionable data may be indicated with an optional grade and comment.

## Model for Habitat Data

Habitat data consist of physical characteristics measured or scored at a sampling site that can be combined into one numerical value in a habitat index. Structural changes were not required to include habitat data in the database. Habitat data can easily be incorporated into the original structure of the FoxDB in *TBLResults*, using appropriate STORET codes. Although many habitat parameters already exist in the FoxDB, new seven-digit codes were created specifically in this project for those habitat parameters not included in the original STORET codes but which are needed for analysis (Table 10). Note that all STORET codes are six-digit numbers. Other reference tables were updated to include proper codes for habitat as a sampling medium and habitat protocols.

**Table 10. New Codes Added to Describe Habitat Parameters**

<u>Parameter Code</u>	<u>Full Name</u>	<u>Parameter Code</u>	<u>Full Name</u>
4000001	QHEI score 0-100	4000025	Substrate Silt/mud (%)
4000002	QHEI substrate score 0-20	4000026	Substrate Sand (%)
4000003	QHEI instream cover score 0-20	4000027	Substrate Fine Gravel (%)
4000004	QHEI channel morphology score 0-20	4000028	Substrate Medium Gravel (%)
4000005	QHEI riparian zone score 0-10	4000029	Substrate Coarse Gravel (%)
4000006	QHEI pool/glide quality score 0-12	4000030	Substrate Small Cobble (%)
4000007	QHEI riffle-run quality score 0-8	4000031	Substrate Large Cobble (%)
4000008	QHEI gradient score 0-10	4000032	Substrate Boulder (%)
4000009	SHAP score	4000033	Substrate Bedrock (%)
4000010	SHAP substrate score	4000034	Substrate Claypan (%)
4000011	SHAP deposition score	4000035	Instream Boulder (%)
4000012	SHAP substrate stability score	4000036	Instream Undercut Bank (%)
4000013	SHAP instream cover score	4000037	Instream Rock ledge (%)
4000014	SHAP pool substrate score	4000038	Instream Submerged tree roots (%)
4000015	SHAP pool quality score	4000039	Instream Brush-debris jam (%)
4000016	SHAP pool variability score	4000040	Instream Logs (%)
4000017	SHAP channel alteration score	4000041	Instream Aquatic vegetation (%)
4000018	SHAP channel sinuosity score	4000042	Instream Submerged terrestrial vegetation (%)
4000019	SHAP width-depth ratio score		
4000020	SHAP hydrologic diversity score	4000043	Instream Other (%)
4000021	SHAP canopy score	4000044	Substrate Plant detritus
4000022	SHAP bank stability score	4000045	Substrate Vegetation
4000023	SHAP land use score	4000046	Substrate Submerged logs
4000024	SHAP flow-related refugia score		

## Model for Biological Data

Raw biological data collected during a sampling event consist of the number of individuals for each species collected (composition of the biological sample). This information is then processed into numerical indexes. These two types of biological data, raw data and metrics or indexes, are stored in two different ways. Numerical indexes can be coded in the same way as other numerical results associated with chemical analyses, provided a proper code exists. The same is true for habitat measurements or indexes. New seven-digit codes were created specifically in this project for those biological indexes not included in the original STORET codes but needed for analysis (Table 11). All new biological index codes start with number 2, and all new habitat codes start with number 4.

**Table 11. New Codes Added to Describe Biological Metrics**

<u>Parameter Code</u>	<u>Full Name</u>
2000001	Number of native species, #/effort
2000002	Number of darter species, #/effort
2000003	Number of sucker species, #/effort
2000004	Number of sunfish species, #/effort
2000005	Number of intolerant species, #/effort
2000006	Percent of tolerant species, %
2000007	Percent of omnivores as individuals, %
2000008	Percent of insectivores as individuals, %
2000009	Percent of top carnivores as individuals, %
2000010	Percent of simple lithophils as individuals, %
2000011	Percent of green sunfish as individuals, %
2000012	Percent of hybrids as individuals, %
2000013	Total number of individuals (w/o hybrids), #/effort
2000014	Total number of species (w/o hybrids), #/effort
2000015	Number of roundbodied suckers as individuals, #/effort
2000016	Percent of roundbodied suckers as individuals, %
2000017	Total number of individuals (w/o hybrids and tolerant species), #/effort
2000018	Total number of species (w/o hybrids or tolerant species), #/effort
2000019	Total number of species (incl. Hybrids), #/effort
2000020	Total number of individuals (incl. Hybrids), #/effort

Several new tables were added to the FoxDB to describe the composition of the biological sample collected at a site (Figure 23). The *Taxa Related* block is integrated into the existing structure of the FoxDB and provides taxonomic information on aquatic biota, presently fish and macroinvertebrates. The structure enables incorporating other taxonomic groups such as algae or macrophytes, provided that corresponding information on species is added to relevant tables. The U.S. Department of Agriculture (USDA) houses the Integrated Taxonomic Information System (ITIS) database, developed to provide accurate, scientifically credible, and current taxonomic data, and serving as a standard to enable the comparison of biodiversity datasets (USDA, 2004). The ITIS taxonomic classification and codes were adopted into the STARED. The ITIS code is similar to the STORET parameter codes in that it basically describes

what can be found or analyzed in a sample. The taxonomic part of the *TBLITIS\_Code* table mimics the ITIS structure, defining a taxonomic hierarchy with Latin and common names, parent taxa, and taxonomic rank. Other information includes the assessment group (fish or macroinvertebrates) and a code specifying whether the species is native. The table *TBLIndices\_Group* assigns species or taxa to the most common groups used in deriving the index of biotic integrity, such as Amphipods or Chironomids for macroinvertebrate indexes and darters or simple lithophilic spawners for fish indexes. Indices also include feeding preferences of the taxa (e.g., collectors, gatherers, herbivores, or insectivores).

Biological “catch” data corresponding to result tables for chemistry data are stored in the *TBLBio\_Taxa* table. For each sample identified by a unique ID, the result is the number of individuals for a species defined by the ITIS Code. The field *Life\_Stage* was included in *TBLBiol\_Taxa* to allow distinction among various life stages of collected individuals, such as adult, immature, or larvae, often reported in biological samples. Life stage codes are defined in *TBLLife\_Stage\_Codes*.

The structure of STARED and, consequently, the updated FoxDB was designed to help calculate metrics describing fish and macroinvertebrate communities in indexes of biotic integrity. The most common characteristics of species are incorporated in the database, including information on feeding preferences, taxonomic groups used in calculating the IBI, and whether the species is native. In addition to taxonomic data, calculated indexes can be entered directly into the database using special parameter codes (Table 11).

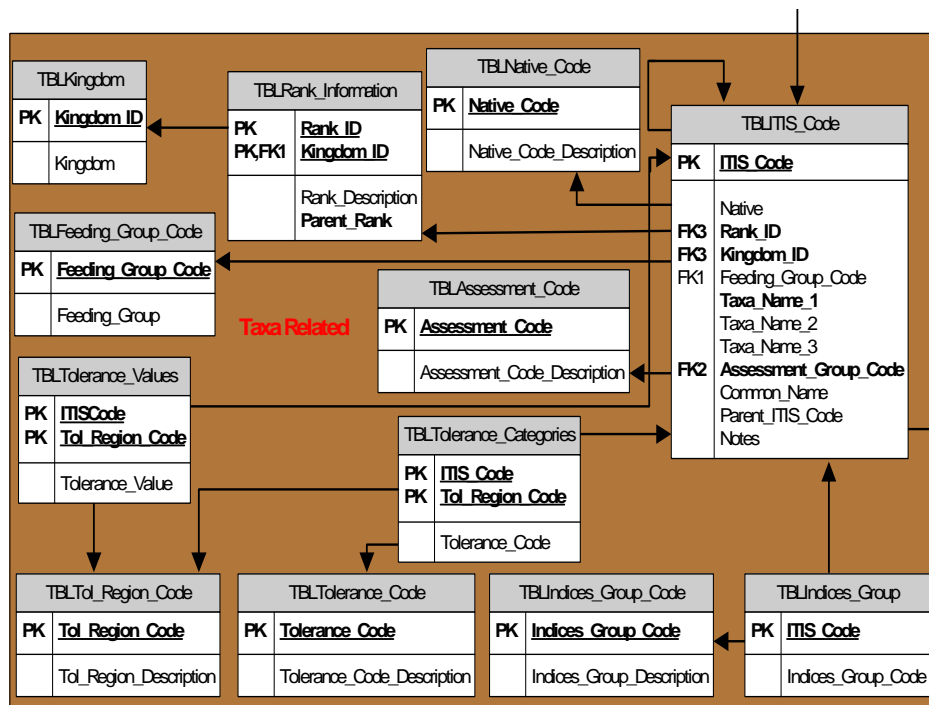


Figure 23. Taxa-related group of tables included in FoxDB

## Summary

This report summarizes biological data in the study area, the Fox River watershed below Stratton Dam to the confluence of the Illinois River. Fish, macroinvertebrate, and habitat data collected by various agencies in the study area were processed, imported to a relational database, FoxDB, and analyzed. A significant change in the FoxDB structure was required to incorporate biological data, including details on abundance and richness of individual species. The updated FoxDB now contains all available data on water quality, sediment quality, habitat, and biology. The new structure also enables direct calculation of metrics needed for IBI calculation.

A related research project on macroinvertebrates and habitat in northern Illinois is summarized. The effect of habitat on macroinvertebrates was thoroughly investigated by the author under Grant No. R83-0885-010 to Northeastern University from the USEPA/NSF/USDA STAR Watershed Program using two approaches: (1) direct multiple regression on habitat variables, stream characteristics, and known toxics (selected heavy metals), and (2) indirect risk-based approach. The direct-effect approach explained a higher percentage of variability in the data.

As each biological index or metric is designed to evaluate a different aspect of the biological community, there is a different level of sensitivity to various disturbances, and not all indicators show a significant difference between sites in selected categories. Two effects were investigated in this report: the effect of flow regime (impounded and free-flowing) and the effect of land use (upper more urbanized part and lower rural part of the watershed). Most biological indicators imply impairment of mainstem sites, especially in the impounded portions of the river, and suggest higher impairment in the upper urbanized part of the watershed.

Change in fish community composition is a good indicator of stream impairment. Top carnivores represent a significantly larger proportion in the mainstem than in tributaries, suggesting a shift in feeding groups. This is also reflected in several other indicators. Populations of minnows representing specialized insectivores are strongly affected both in terms of number of species and percent of individuals caught in the mainstem sample. Tributaries in the upper part of the Fox River watershed also show lower values for minnows, though not as low as in mainstem sites. A similar distinction between sites in the upper and lower parts of the Fox River was observed for the proportion of lithophilic spawners.

Impounded mainstem sites show a significantly lower number of species and an increased proportion of omnivores. The proportion of lithophilic spawners is decreased in impounded sites. Habitat index is also lower for the impounded sites. Additional study is recommended to evaluate the combined effect of habitat, change in flow regime, and water and sediment quality on fish communities.



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## APPENDIX A: Spatial Distribution of Fish Metrics

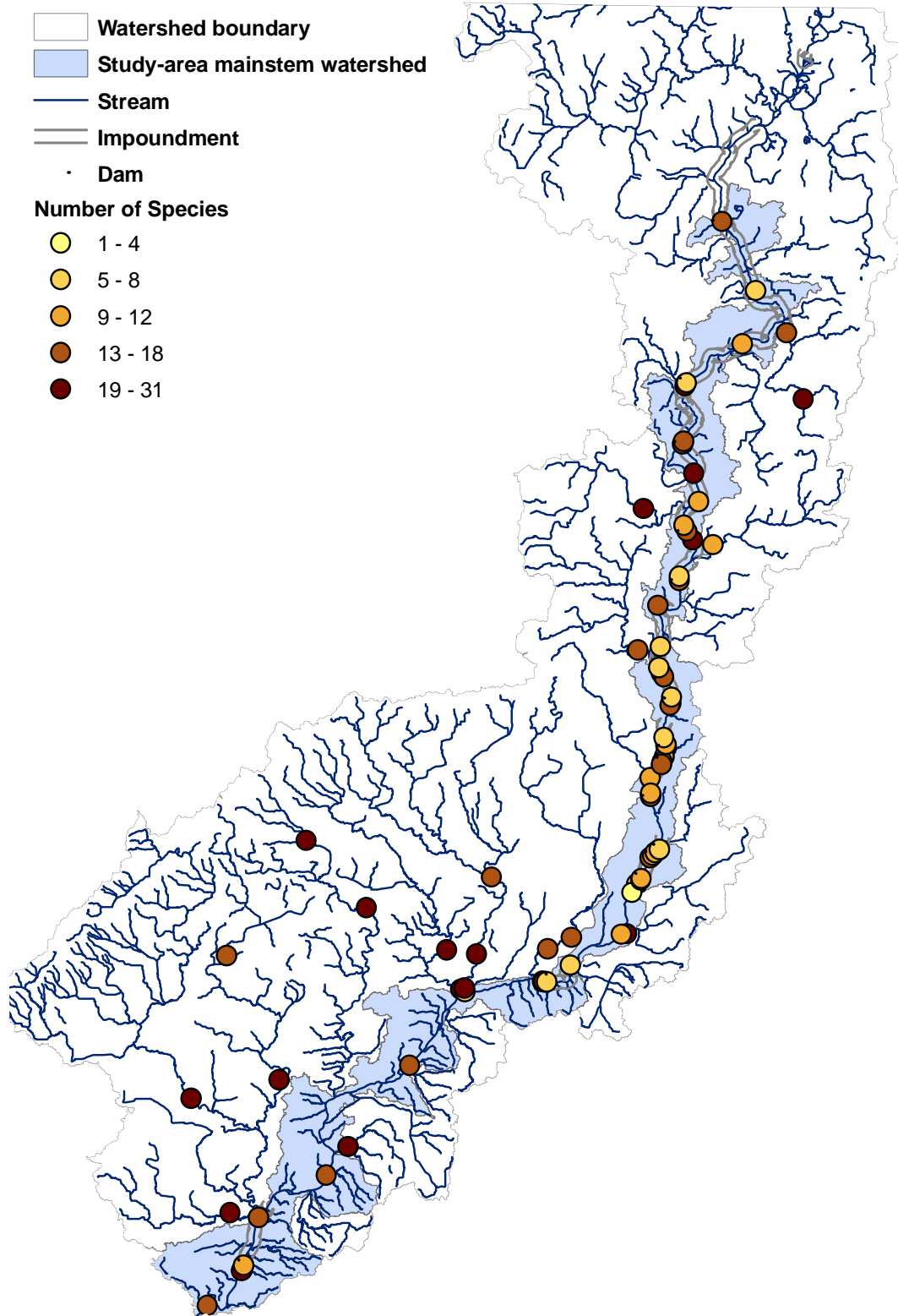


Figure A-1. Spatial distribution of number of species in the study area

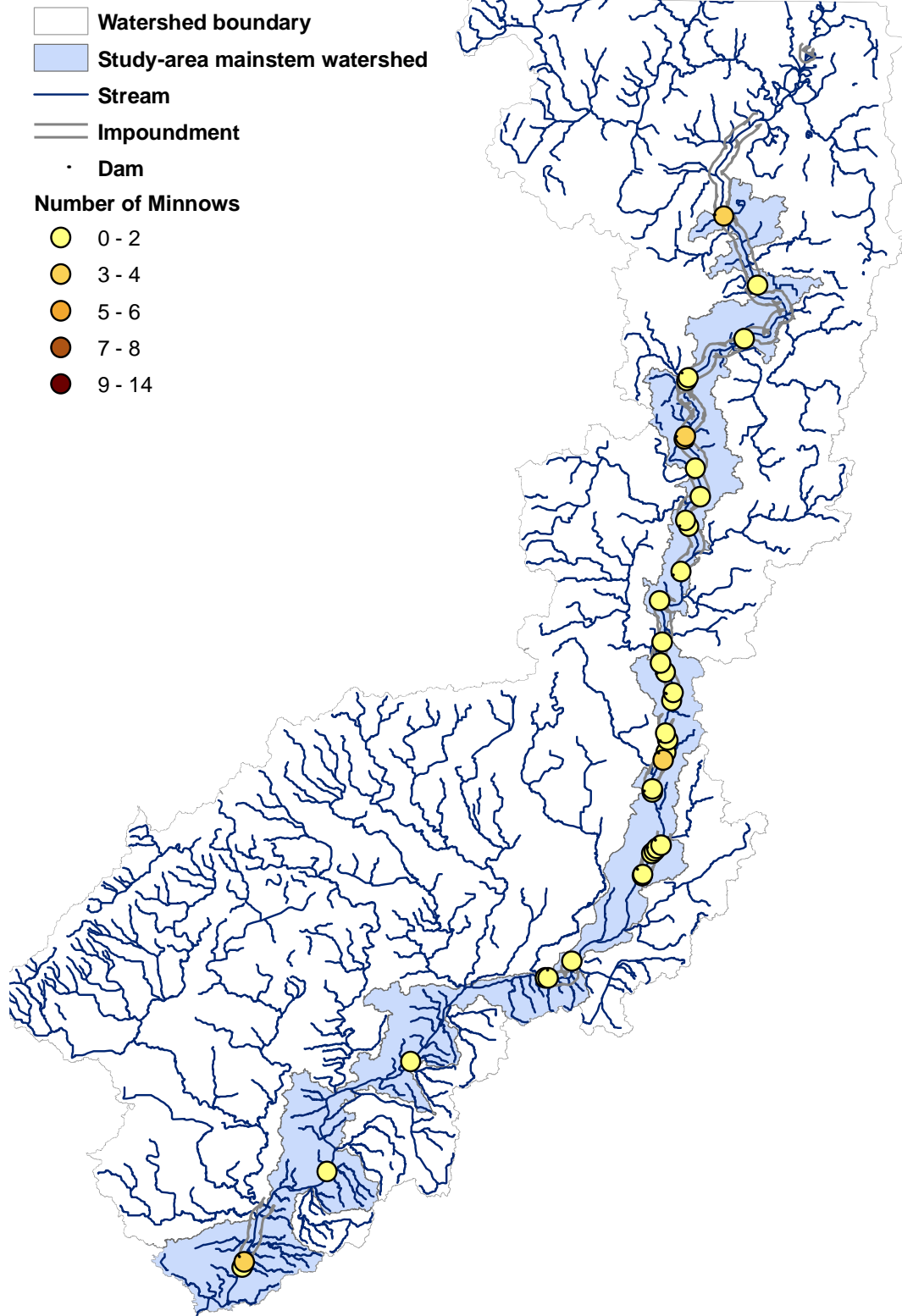


Figure A-2. Spatial distribution of number of minnow species in the study area

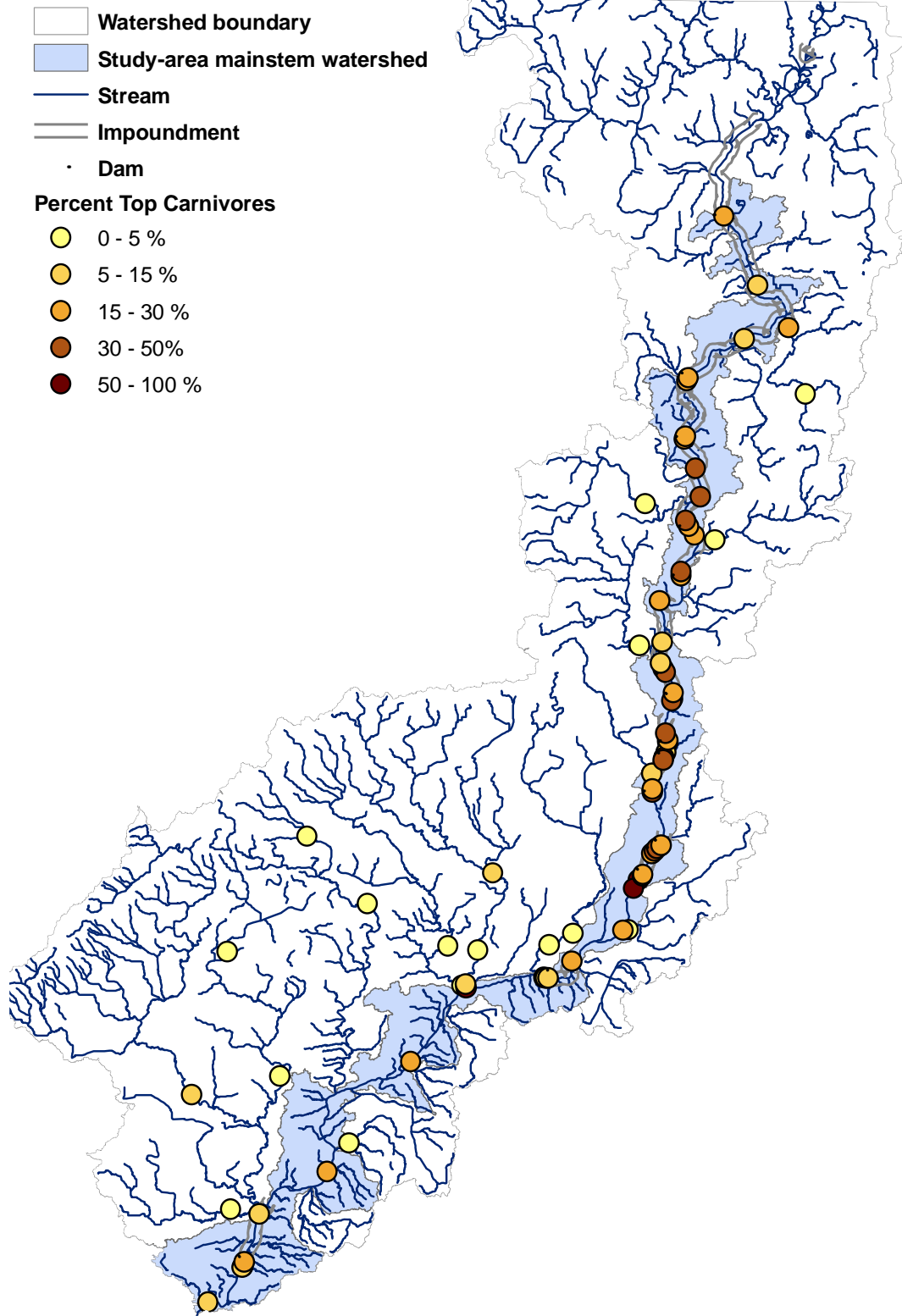


Figure A-3. Spatial distribution of proportion of top carnivores in the study area

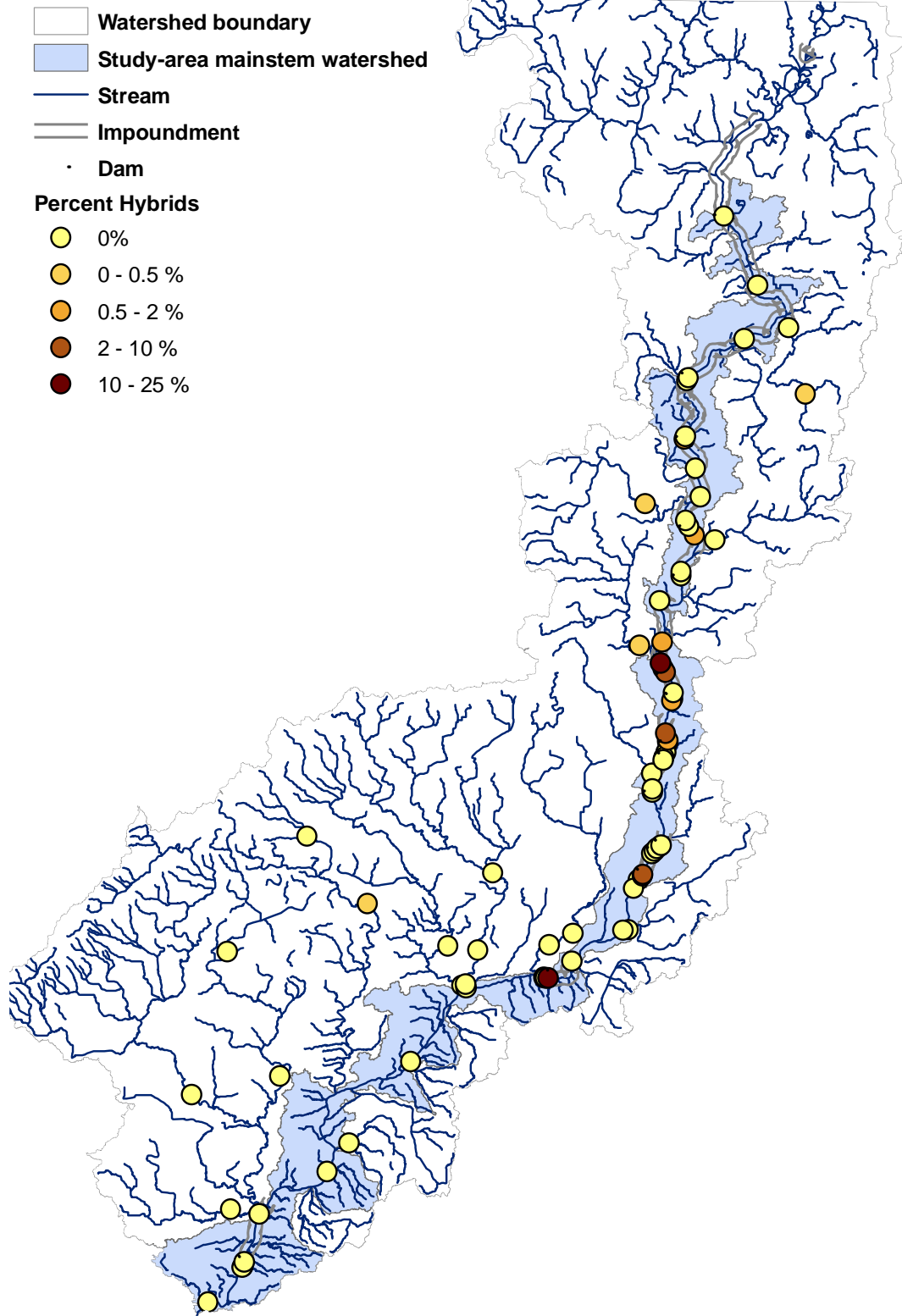


Figure A-4. Spatial distribution of proportion of hybrids in the study area

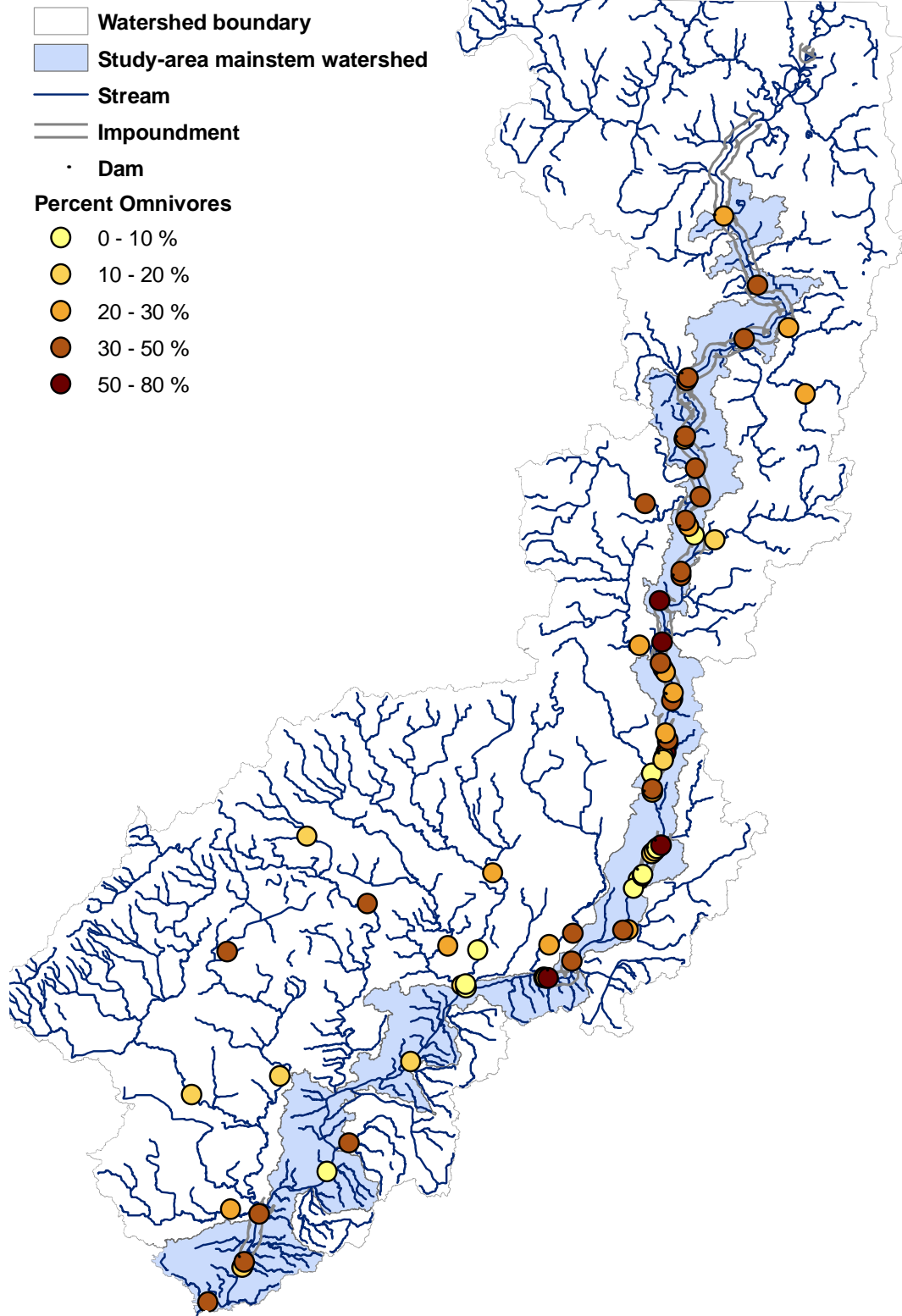


Figure A-5. Spatial distribution of proportion of omnivores in the study area

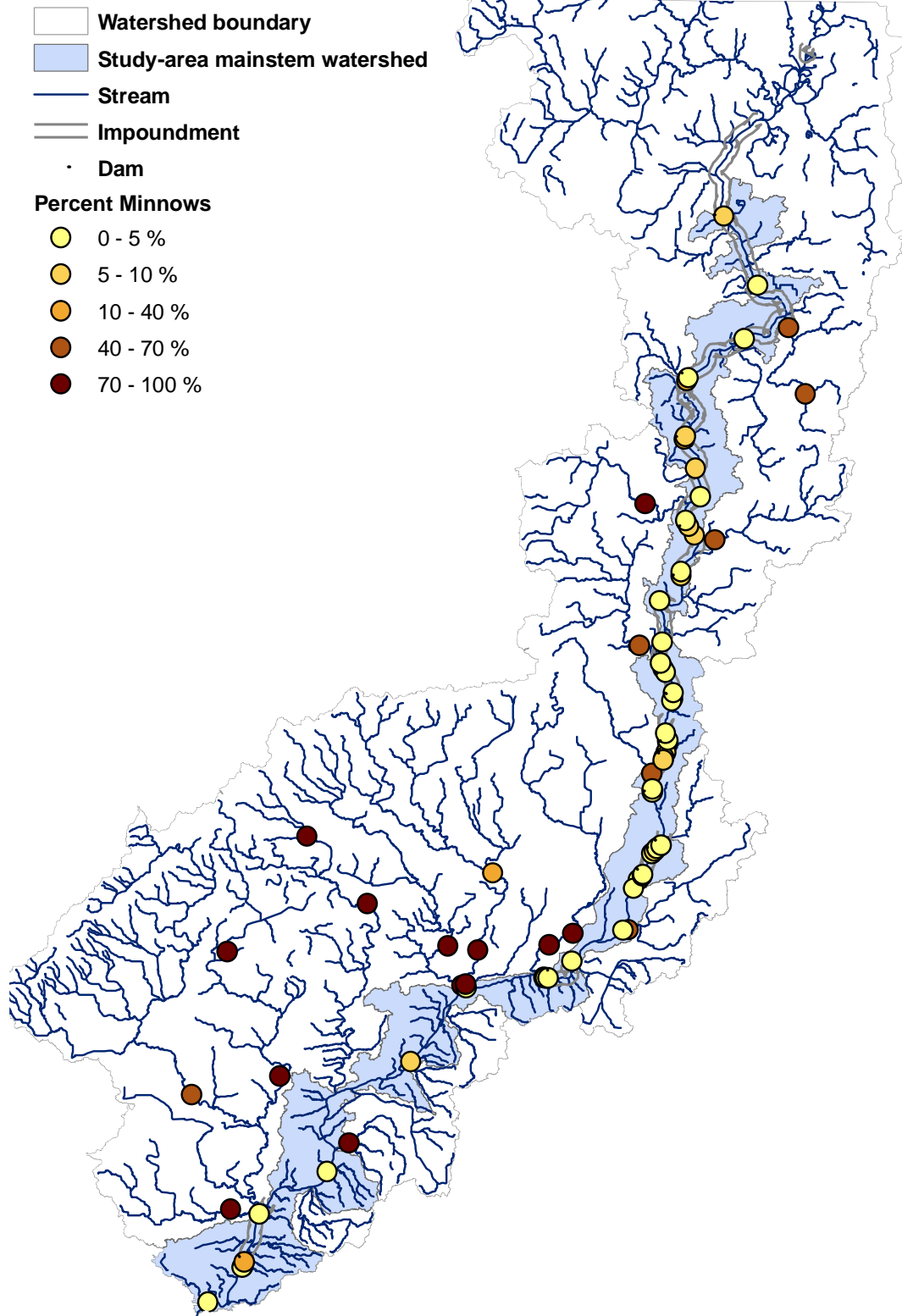


Figure A-6. Spatial distribution of proportion of minnows in the study area

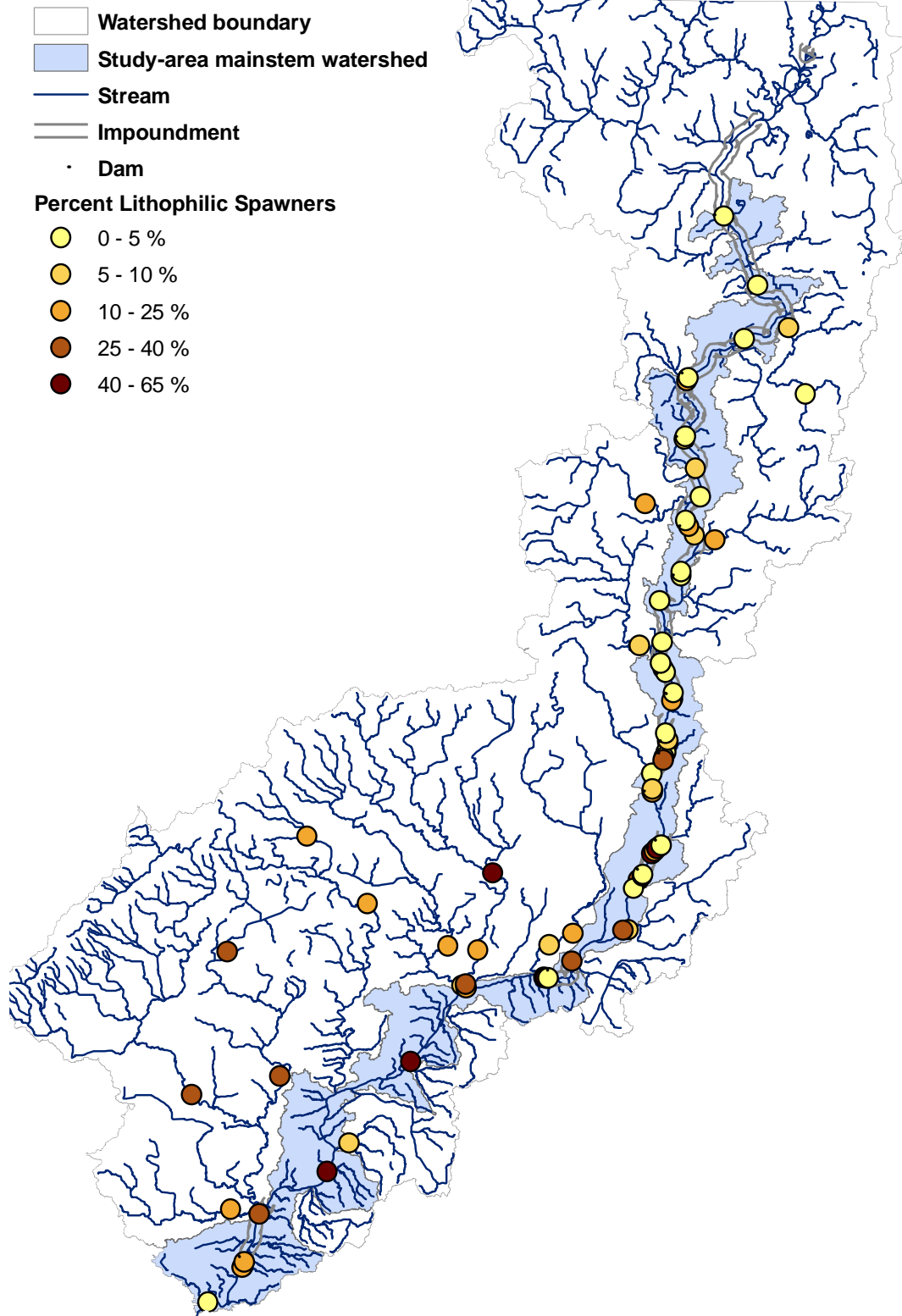


Figure A-7. Spatial distribution of proportion of lithophiles in the study area

