Summary of Findings from the 2020-2021 Aquatic Life and Water Quality Survey of Ohio's Large Rivers

The Maumee River near Hedges Island

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Division of Surface Water
Assessment and Modeling Section
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Special thanks to the field staff, especially given the unique set of circumstances in 2020 and 2021. The primary author of this document was Robert Miltner with contributions from Chuck Boucher, David Brumbaugh, Rich Budnik, Kelly Capuzzi, Mike Gallaway, Paul Gledhill, Mandy Razzano, Rachel Taulbee, and Chloe Welch.

The Mad River near Dayton

Foreword

Midwest Biodiversity Institute (MBI) provided comments on the draft version of this report, noting that additional details on the events leading up to the improvements in water quality in Ohio's large rivers should be included in the report. With MBI's approval, this adapted version of their additional details is included as a foreword in this final report.

By Chris O. Yoder, Research Director, Midwest Biodiversity Institute, on behalf of the numerous others who participated and drove the events detailed below.

A complete and accurate documentation of the course of important events leading to improvements observed and reported by the 2020-21 survey is needed to fully appreciate how much was accomplished. While the report generally acknowledges the role of one past program in accomplishing the level of pollution abatement that is related to the majority of the biological and chemical improvements, it lacks important details that most of today's readers, environmental professionals, policy makers, and the public in general are largely unaware. These events include:

- The 1978 Ohio Water Quality Standard (WQS) that introduced the concept of tiered aquatic life uses and modernized water quality criteria for parameters such as dissolved oxygen, ammonia-N, and selected heavy metals that later became the basis for Water Quality Based Effluent Limits (WQBELs).
- The U.S. EPA promulgation of WQS in 1978-79 that disapproved the numerous Limited Warmwater Habitat (LWH) reaches designated by Ohio EPA that had reach-specific chemical criteria accommodating secondary treatment[1] at Publicly Owned Treatment Works (POTWs) and that also accommodated plant bypasses and CSOs. This action replaced LWH segments with a Warmwater Habitat (WWH) designation. U.S. EPA had also disapproved the WWH dissolved oxygen criteria of 5 mg/l average/4 mg/l minimum opting for a strict 5 mg/L minimum. However, U.S. EPA eventually acceded to the Ohio EPA criteria in the end. This and the ammonia-N criteria based on pH and temperature provided the basis for WQBELs that eventually led to the reductions in loadings of biochemical oxygen demand and ammonia-N that spurred the entirety of the biological improvement that was first witnessed in the early 1990s and more fully in 2010 when 93% of large river miles attained their designated aquatic life use as reported in the 2010 Integrated Report[2].
- The critical role of the National Municipal Policy and Strategy for Construction Grants[3], National Pollution Discharge Elimination System (NPDES) Permits, and Enforcement Under the Clean Water Act that set a deadline of July 1, 1988, for POTW compliance with WQBELs merits central attention in the large rivers report. While the report acknowledges the role of the former Construction Grants Program and its current day replacement, the State Revolving Loan Fund Program, it is doubtful that most readers will make the connection back to this policy. It was in fact a mandate that states and municipalities initially objected to, but the U.S. EPA of that day was a different entity and had the clout to force compliance with water quality-based treatment requirements. In the end, Ohio EPA and the municipalities carried out that mandate which accounted for the vast majority of the improvement witnessed through the early 2000s and continuing today. This was much more than

[1] Secondary treatment is a lower level of pollution removal than what is now currently practiced.

[2] The miles of attainment for large rivers reported in past Integrated Reports were based on a rolling 10-year average of surveyed segments, and thus biased upward or downward by the most recent surveys added or the oldest surveys subtracted.

[3] ***https://www.epa.gov/enviro/igms-construction-grants-overview***

the funding incentive posed by the Construction Grants program, but a revolution in NPDES permitting beyond mere technological limitations represented by WQBELs.

- The Construction Grants Program also provided the initial support for what became Ohio's intensive survey program and rotating basin approach to monitoring and assessment via Section 205[g] funding. This monitoring program provided the critical baseline data for documenting the severity and extent of impairments and eventually tracked the improvements that resulted incrementally after 1988. It also supported the implementation of Ohio's tiered aquatic life uses by conducting numerous Use Attainability Analyses (UAAs) that settled the question of which WQS applied to a given NPDES permit and providing a means to justify upgrading uses where documented improvements had occurred. Some of those improvements did not become completely visible until well into the 2010s.
- The Cuyahoga River use designation hearing at the Ohio Environmental Board of Review in 1989[4], solidified the system for designating rivers and streams using the intensive survey results and the upgrading of former LWH segments to WWH or better. Any other ruling could have diminished or precluded the roll out of WQBELs that followed. There were at least three subsequent court decisions that bolstered the bioassessment and biocriteria program, but the Cuyahoga case was the linchpin.
- The Ohio NPDES wastewater fee program in the 1990s allowed support for WQS and the monitoring assessment program to continue when Construction Grants Program funding ended. This allowed the improvements triggered by WQBELs developed in the 1980s to be followed through the 1990s and 2000s.

The point of stating all of the above is to ensure that credit for the improvements extolled in the large rivers report is assigned to the events that were critical "forks in the road," any one of which if done differently could have precluded today's success story.

[4] Also known as Northeast Ohio Regional Sewer District vs. Shank No. 89-1554, Supreme Court of Ohio, February 27, 1991.

Executive Summary

In large rivers, a great deal of continuity is expected in the types of fish or macroinvertebrates one finds from one location to the next. In general, and in the absence of any perturbation or obvious source of discontinuity (e.g., a major tributary joining up), very little change is expected to occur over the course of seven to 10 miles. Thus, given the 1,372 free-flowing miles of large rivers in Ohio, a census of the biological condition of our rivers is possible by evenly distributing sites across those miles. During the 2020 and 2021 field seasons, Ohio EPA conducted a biological census of large rivers across the state. This census was accompanied by observations of water quality, sediment chemistry, and whole-body fish tissue for contaminant analysis. The census used 156 sites spaced at intervals of approximately 8.8 miles (Figure 1; Appendix A). The goals of the census were twofold: 1) to obtain a complete picture of the status of Ohio's large rivers to serve as baseline for future comparisons and to gauge progress in water quality improvements relative to prior surveys; and 2) to identify the major remaining stressors impacting water quality and biological condition. The following report summarizes results for aquatic life and sport fish tissue analysis. Additional information, including recreation use analysis, will be available in the 2024 Integrated Water Quality and Assessment Report.

Major Findings

- The biological condition of Ohio's large rivers has improved dramatically since surveys were first conducted in the 1980s. Eighty-nine percent of the miles surveyed met expectations, and were judged to be in good to excellent condition. For comparison, in the 1980s, only 18 percent of the surveyed miles met expectations. The dramatic reversal is the direct result of investments in improved wastewater infrastructure and treatment, and agricultural soil conservation measures.
- Over-enrichment was identified as the most pervasive stressor impacting water quality, and in some instances, biological condition. The over-enrichment of our large rivers is characterized by excessive levels of phosphorus and nitrogen, and high biological oxygen demand.
- Legacy pollution from coal mining and heavy industry remains detectable in water quality and sediment samples, but causes only modest impact to aquatic life.
- Our large rivers are getting warmer. Water temperatures observed in the Ohio EPA data have increased successively over each decade surveyed. In the 1980s, the average temperature for the months of June-September was 21.7^{0} C. The average temperature obtained from the 2020-2021 survey was 23.3^{0} C.
- The Mohican River was the only river to show a significant decline in condition. This decline was due to over-enrichment and sediment.

Over-enrichment and warming stream temperatures can both be partially mitigated by improving the physical habitat quality and the riparian buffers of headwaters feeding our large rivers.

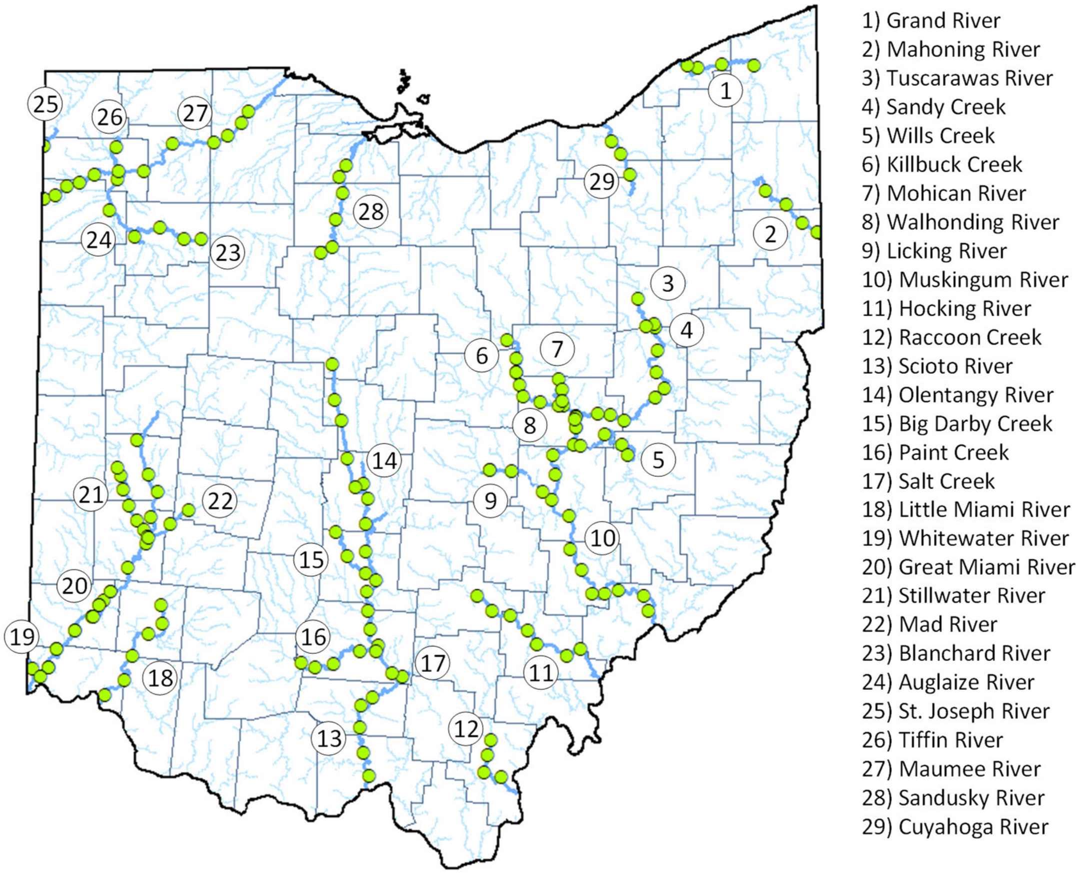


Figure 1 – Ohio's large rivers and sampling locations included in the 2020-2021 survey.

Clean Water Act Attainment Status of Ohio's Large Rivers

Ohio defines attainment status based on the outcomes from biological surveys. Numeric scores reflecting the health of macroinvertebrates and fish are compared to statutory benchmarks. If scores for both macroinvertebrates and fish meet the benchmarks, full attainment of a waterbody is demonstrated. If both scores fail the benchmarks, the waterbody is in non-attainment. If one indicator fails the benchmark, attainment is partial. Waters in partial or non-attainment are considered impaired.

The attainment status of Ohio's large rivers has improved dramatically over the 40 years since monitoring began (Figure 2)[5]. In the 1980s, 82 percent of the 1,372 miles of our free-flowing rivers fell below acceptable standards established by the Clean Water Act and the State of Ohio, and in many instances that impairment was egregious, having been caused by toxic chemicals or sewage. Today witnesses a complete reversal. Eighty-nine percent of the miles meet established standards, whereas 11 percent are impaired, and in most of those instances the impairment is modest and not related to toxic pollutants or sewage. The reversal is largely attributable to two programs: the construction grants program implemented during the 1980s which upgraded and modernized sewage collection and treatment (now referred to as the state revolving fund), and the implementation of soil conservation measures during the 2000s. These programs reduced the amount of poorly treated sewage and sediment that formerly degraded and clogged our rivers. On-going efforts, especially those directed at mitigating impacts from combined sewer overflows (CSOs)

[5] The miles apportioned into attainment status for each time period was done in ArcGIS v.10.7.

and removal of low-head dams have also been significant factors contributing to recovery. It should also be noted that stormwater management is now considerably better than in the past, and likely helps support water quality in our large rivers, but the relative influence is unknown.

Today, the main cause of impairment is over-enrichment from phosphorus and fertilizers. That said, the legacy of past mining and industrial pollution remains detectable in several of our rivers, whether that legacy results in impairment or not. Elevated sediment metal concentrations in the Mahoning River continue to impact benthic invertebrates. Sediment metal concentrations were also elevated in the Tuscarawas River, but that was unaccompanied by biological impairment. Raccoon Creek and Wills Creek both showed modest impairment in the fish community due to sedimentation and water column metals originating from mining. Figure 3 maps the attainment status of Ohio's large rivers. Table 1 lists the attainment status by individual sampling location.

Most of our large rivers are enriched with excessive levels of nutrients, especially phosphorus, and in some cases nitrogen. Phosphorus and nitrogen stimulate the growth of algae, bacteria, and fungi. Rivers breathe in air and exhale carbon dioxide in a manner analogous to humans. When nutrients stimulate the growth of the microbial community, the metabolism of the river heats up and respiration increases. If the metabolic rate is too high, the river, including the fish and macroinvertebrates living there, become stressed. This condition is known as being over-enriched or hypertrophic. Ohio EPA, as well as other states and researchers have identified water quality hallmarks for diagnosing when the metabolic rate of a river is being pushed too hard. These markers include how much dissolved oxygen and pH fluctuate over the course of 24 hours, the amount of biological oxygen demand (i.e., how much oxygen is needed to sustain the metabolic rate), chlorophyll concentrations to indicate how much algae have been stimulated, and total Kjeldahl nitrogen (TKN) concentrations to indicate how much the overall microbial community has been stimulated.

In general, phosphorus concentrations greater than 0.13 mg/L in large rivers are excessive and have the potential to cause over-enrichment. When that potential is being realized, chlorophyll concentrations will rise above 30 ug/L, and may go higher than 100 ug/L as the river becomes hypertrophic. Elevated TKN concentrations, defined as concentrations greater than ~1 mg/L, can be generated by growths of algae and other microbiota in the river, but can also signify organic enrichment from outside sources such as manure or upstream impoundments. A TKN concentration greater than 1 mg/L is generally associated with biological impairment when the TKN is generated within the river or from manure or raw sewage. Note, however, that TKN is also a component of treated wastewater, but in that case, the TKN represents nitrogen compounds that are resistant to being broken down and utilized by bacteria or algae for growth, and so does not generally pose a risk for impairment in that case.

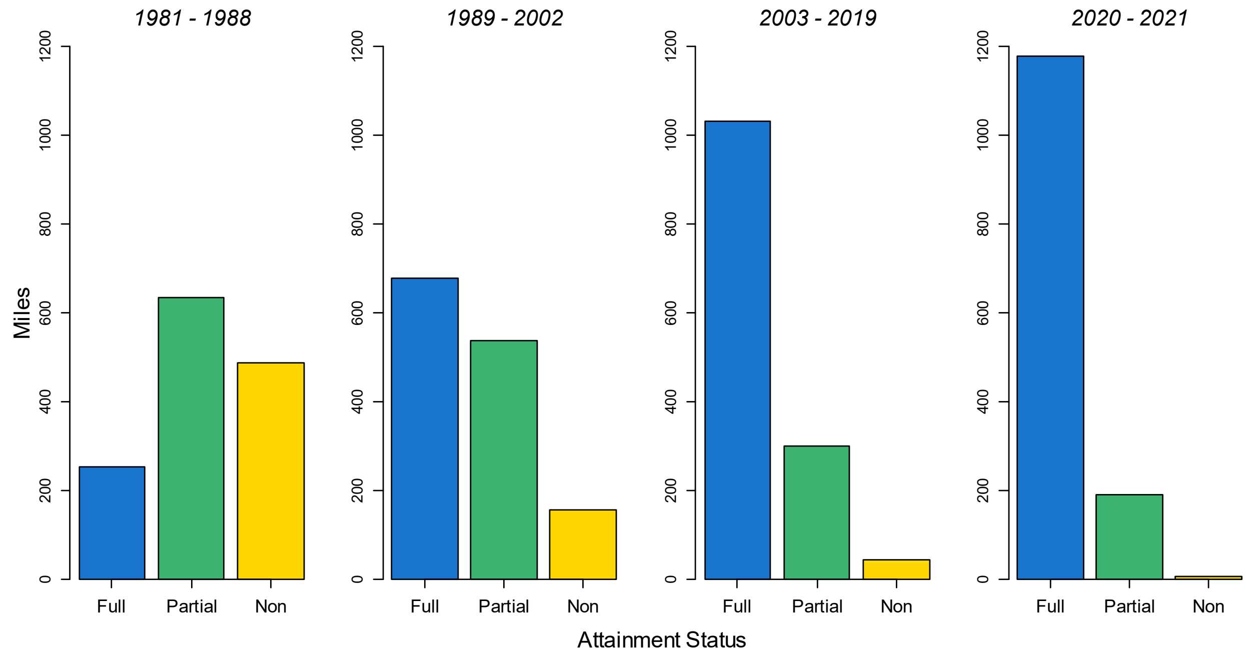
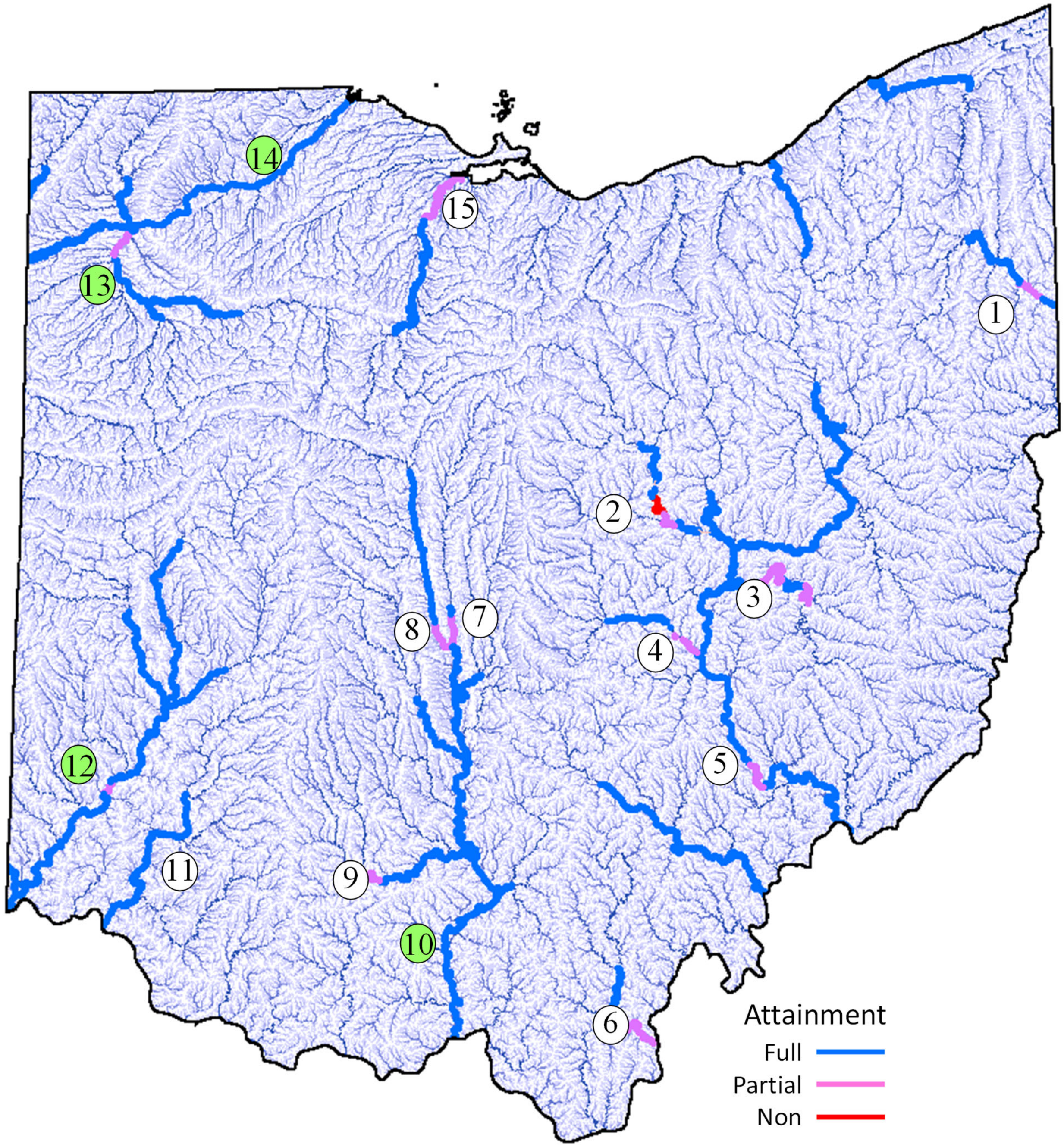


Figure 2 - The number of river miles categorized by attainment status over four relevant time periods.

Surveys conducted between 1981-1988 were prior to major improvements in wastewater treatment. Surveys between 1989-2002 were after major wastewater improvements but prior to implementation of agricultural soil conservation practices. Surveys between 2003-2019 reflect the combined effect of improved wastewater treatment and soil conservation. The 2020-2021 survey reflects a continued positive trajectory in our large rivers.

With respect to the other aforementioned markers, 5-day biological oxygen demand (BOD5) concentrations greater than 6 mg/L are typically associated with biological impairment, and are an indication of hypertrophic conditions or egregious levels of organic enrichment from raw sewage. BOD5 concentrations greater 3 mg/L indicate over-enrichment. When measured at hourly intervals over a 24-hour period, dissolved oxygen concentrations fluctuations (i.e., the range between the morning low and the afternoon high) greater than 7 mg/L indicate enrichment, and greater than 9 mg/L indicate hypertrophic conditions. In daytime-only grab samples, dissolved oxygen super-saturation, defined here as greater than 120 percent saturation, is another good indicator of over-enrichment. Similarly, wide fluctuations in pH are driven by high rates of photosynthesis, and daytime observations greater than 8.7 indicate over-enrichment, and observations greater than 9.0 exceed the established water quality standard for pH. Figures 4 and 5 show the concentrations of enrichment indicators by river obtained from the 2020-2021 survey. The aquatic life use in segments with multiple indications of over-enrichment or hypertrophic condition is likely threatened. Segments within the Auglaize River, Maumee River, Great Miami River and Scioto River have these indications.



1 - Mahoning River; sediment metals
2 - Walhonding & Mohican Rivers; organic enrichment
3 - Wills Creek; sediment and metals (mining legacy)
4 - Licking River; eutrophication
5 - Muskingum River; eutrophication
6 - Raccoon Creek; metals
7 - Olentangy River; urban stormwater
8 - Scioto River; nutrient & organic enrichment
9 - Paint Creek; tailwaters (enrichment from reservoir)
10 - Lower Scioto River; hypertrophic
11 - Little Miami River; nutrient & organic enrichment
12 - Great Miami River; hypertrophic
13 - Auglaize River; nutrient & organic enrichment
14 - Maumee River; nutrient & organic enrichment
15 - Sandusky River; nutrient & organic enrichment

Figure 3 - The attainment status of Ohio's large rivers. River segments with impairments or threatening stressor levels are labeled and the observed stressors are noted. Green circles indicate hypertrophic condition.

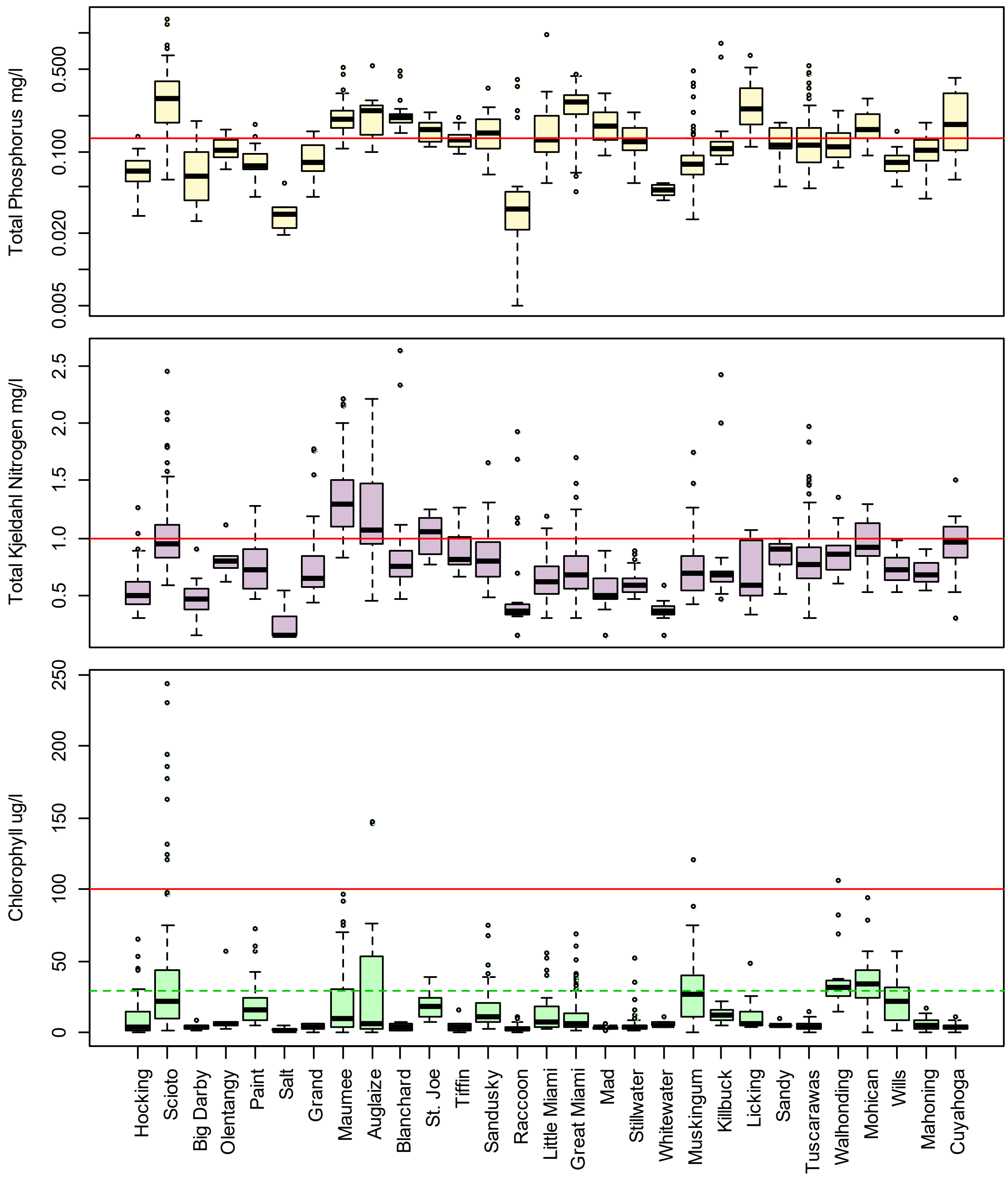


Figure 4a - Distributions of enrichment indicators measured during the 2020-2021 Large River survey.

The red line in the total phosphorus plot is drawn at 0.13 mg/L and potentially denotes excessive concentrations. The red line in the TKN plot denotes concentrations that are potentially deleterious to aquatic life. The dashed green line in the chlorophyll plot is drawn at 30 ug/L and represents highly eutrophic conditions, and the red line indicates hypertrophic conditions.

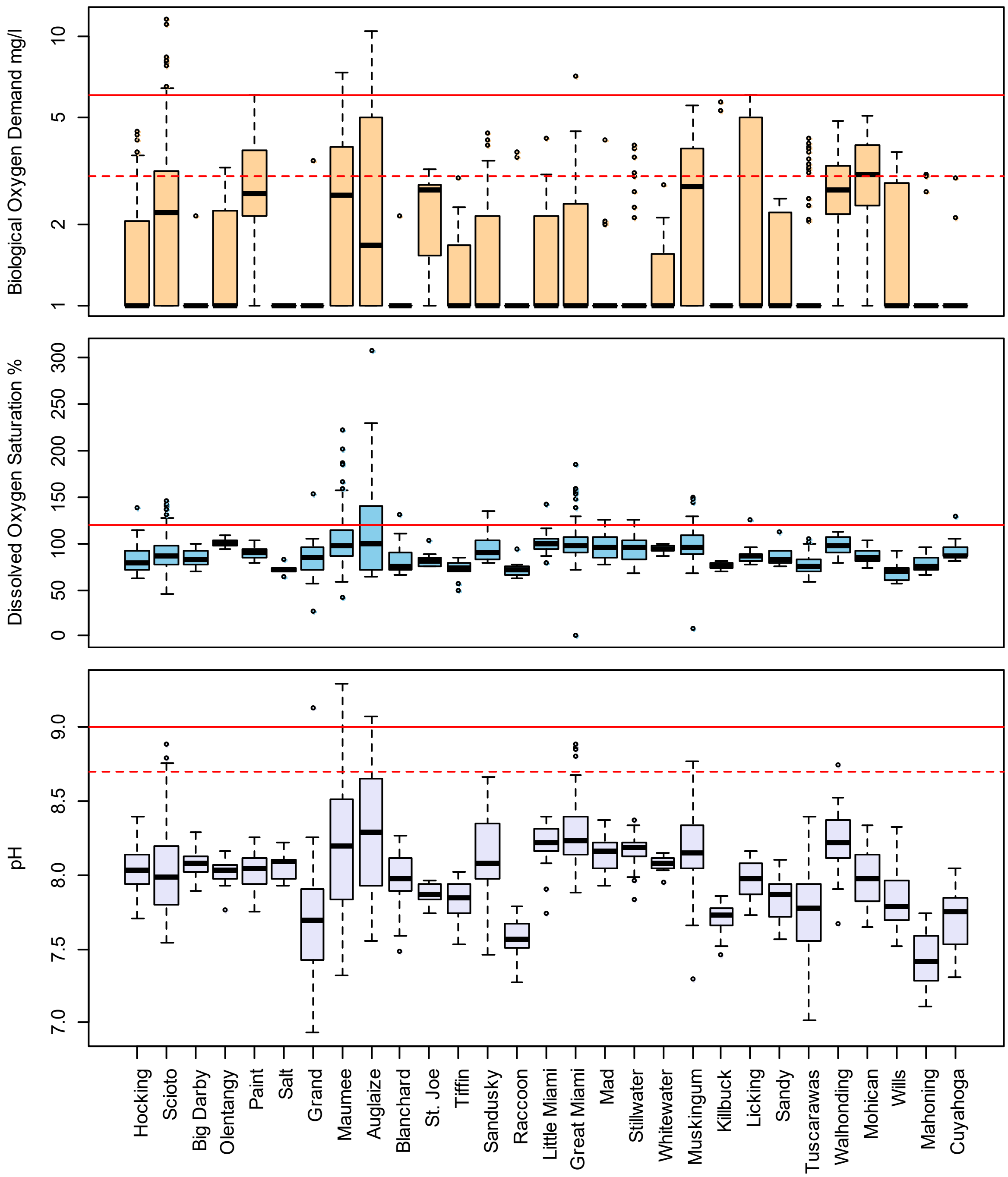


Figure 3b - Distributions of additional enrichment indicators measured during the 2020-2021 Large River survey.

The dashed red line in the BOD5 plot denotes over-enrichment; concentrations exceeding the solid red line are deleterious. The red line in the dissolved oxygen saturation plot is drawn at 120 percent and indicates supersaturation associated with highly eutrophic conditions. The dashed-red line in the pH plot denotes highly eutrophic conditions, and the solid red line is drawn at the water quality standard for pH.

Table 1 - Attainment status of Ohio's large rivers surveyed in 2020 and 2021.

Acronyms used in the table header are as follows: STORET – an alphanumeric code used as a site identifier; RM – river mile, as the distance from the downstream confluence with the next major river; DA – drainage area in square miles; IBI – fish Index of Biotic Integrity score; MIWB – fish Modified Index of Well-being score; ICI – Invertebrate Community Index score; EPT – total taxa richness for insects in the orders Ephemeroptera, Plecoptera, and Trichoperta; ECO – ecoregion; ALU – existing aquatic life use designation; Attain – aquatic life use attainment status.

STORET	RM	DA	IBI	MIWB	ICI	EPT	Year	ECO	ALU	Attain
Hocking River (01-001-000)										
J02W01	68.33	510	52	10.4	E	34	2021	WAP	WWH	Full
J02K06	60.76	562	48	9.6	46	31	2021	WAP	WWH	Full
J02K04	52.8	577	48	9.7	E	28	2021	WAP	WWH	Full
J02P23	44	721	46	9.7	E	32	2021	WAP	WWH	Full
J02S15	33.03	942	46	10.2	48	35	2021	WAP	WWH	Full
J03P15	20.6	982	44	10.2	54	25	2021	WAP	WWH	Full
J03S10	13.56	1141	38	8.8	E	24	2021	WAP	WWH	Full
Scioto River (02-001-000)										
V02W23	175.75	526	44	8.4	46	14	2021	ECBP	WWH	Full
V02P15	163.8	660	46	9.9	48	23	2021	ECBP	WWH	Full
201823	157.1	764	48	9.5	48	28	2021	ECBP	WWH	Full
V03P30	145.57	990	46	9.8	32	16	2021	ECBP	WWH	Full
V03W25	136.5	1049	48	9.7	28*	11	2021	ECBP	WWH	Partial[Ɛ]
600860	129.48	1617	50	10.9	40	21	2021	ECBP	WWH	Full
600810	119.9	1697	52	11.2	40	28	2021	ECBP	WWH	Full
600910	109.37	2311	50	10.9	54	25	2021	ECBP	EWH	Full
600960	99.82	3217	52	11.1	48	33	2021	ECBP	EWH	Full
201818	94.2	3242	54	10.8	50	NA	2021	ECBP	EWH	Full
600940	86.4	3348	45	10.4	50	28	2021	ECBP	EWH	Full
201813	77.4	3828	50	10.9	50	32	2021	ECBP	EWH	Full
V13S09	67.82	3853	48	10.8	50	30	2021	WAP	EWH	Full
600770	56.17	5131	52	11.3	52	29	2021	WAP	EWH	Full
201807	40	5750	50	10.9	52	30	2021	WAP	WWH	Full
201805	33	5837	48	10.9	40	24	2021	WAP	WWH	Full
V15P15	24.5	6086	48	10.2	44	26	2021	WAP	WWH	Full
V15K02	14.67	6174	46	9.8	E	30	2021	WAP	WWH	Full
V15W01	5	6479	48	9.9	52	24	2021	WAP	WWH	Full
Big Darby Creek (02-200-000)										
V07S03	23.75	501	56	10.9	54	34	2021	ECBP	EWH	Full
601300	13.36	534	50	11	54	40	2021	ECBP	EWH	Full
600970	3.2	552	52	10.4	52	29	2021	ECBP	EWH	Full
Olentangy River (02-400-000)										
V04S16	2.7	537	36*	9	40	23	2021	ECBP	WWH	Partial[ƚ]
Paint Creek (02-500-000)										
300053	39.14	570	46	10.5	26*	15	2021	ECBP	EWH	Partial[Ɛ]
V10S28	31.68	773	54	11.4	48	33	2021	WAP	EWH	Full
304031	23.5	827	46	10.5	46	0	2021	WAP	EWH	Full
V10K17	8.9	895	48	10.8	54	40	2021	WAP	EWH	Full
V10W12	1.2	1143	42	10.6	40	29	2021	WAP	WWH	Full
Salt Creek (02-600-000)										
V11G02	1.38	551	50	11.6	46	31	2021	WAP	EWH	Full
Grand River (03-001-000)										
G02G15	40.1	522	50	9.1	48	33	2021	EOLP	EWH	Full

STORET	RM	DA	IBI	MIWB	ICI	EPT	Year	ECO	ALU	Attain
502510	22.46	581	48	9.9	E	33	2021	EOLP	EWH	Full
G02W14	13.7	630	54	10.8	52	37	2021	EOLP	EWH	Full
G02S13	6.1	687	52	10.2	52	35	2021	EOLP	EWH	Full
Maumee River (04-001-000)										
P06K10	107.1	2119	42	8.8	48	28	2021	HELP	WWH	Full
201868	99	2129	44	9.7	E	28	2021	HELP	WWH	Full
P06S08	91.48	2134	36	8.6	46	24	2021	HELP	WWH	Full
P06K06	85.26	2203	40	8.4	50	24	2021	HELP	WWH	Full
P06S07	76.15	2292	36	8.8	52	21	2021	HELP	WWH	Full
201858	58.5	5548	48	10.4	30	15	2021	HELP	WWH	Full
P09P02	44.35	5681	39	9.3	14*	6	2021	HELP	MWH	Full[ŧ]
P11K33	31.64	6058	42	11.1	30	16	2021	HELP	WWH	Full
P11K31	26.7	6264	40	10.5	E	20	2021	HELP	WWH	Full
500080	20.68	6330	42	10.7	40	14	2021	HELP	WWH	Full
301740	16.52	6340	46	10	40	14	2021	HELP	WWH	Full
Auglaize River (04-100-000)										
500110	28.5	719	46	11	46	30	2021	HELP	WWH	Full
P06S10	14.94	2041	38	10.2	16*	5	2021	HELP	MWH	Full[ŧ]
500290	4.14	2330	41	10.2	14*	8	2021	HELP	WWH	Partial[ε]
Blanchard River (04-160-000)										
P05S03	35.24	508	47	9.9	52	25	2021	HELP	WWH	Full
500100	28.88	624	45	9.5	54	23	2021	HELP	WWH	Full
P05S01	13.37	704	40	8.9	46	12	2021	HELP	WWH	Full
St. Joeseph River (04-400-000)										
510220	42.34	609	48	9.5	34	12	2021	ECBP	WWH	Full
Tiffin River (04-600-000)										
P07K01	14	562	40	9.5	NA	NA	2021	HELP	WWH	Full
500160	0.89	775	34	8.4	22	5	2021	HELP	MWH	Full
Sandusky River (05-001-000)										
U03G01	65.01	656	52	9.8	40	25	2021	ECBP	WWH	Full
U04S29	57.34	760.1	52	9.9	E	21	2021	ECBP	WWH	Full
U04S28	41.84	964.2	54	10.5	E	25	2021	ECBP	WWH	Full
500910	30.85	1048.2	54	11.4	32	15	2021	ECBP	WWH	Full
U04Q06	23	1072	54	10.4	50	22	2021	HELP	WWH	Full
U04S23	17.7	1255.3	46	10.5	26*	14	2021	HELP	WWH	Partial[ε]
Raccoon Creek (09-500-000)										
W03S44	35.61	542	49	9.5	42	24	2021	WAP	EWH	Full
601400	29.2	586	50	9.8	44	22	2021	WAP	EWH	Full
303503	22	615	51	9.9	48	22	2021	WAP	EWH	Full
W03S24	10.2	648	39*	8.7*	48	30	2021	WAP	EWH	Partial[ε]
Little Miami River (11-001-000)										
M05K01	50.25	658	54	11.4	48	26	2020	ECBP	EWH	Full
M05S12	43.76	680	50	11.1	54	21	2020	IP	EWH	Full
610520	35.98	964	52	11.1	52	26.5	2020	IP	EWH	Full
M05W34	24.1	1085	45	11.5	50	29	2020	IP	EWH	Full
M05P11	13.07	1203	48	10.3	40*	23	2020/21	IP	EWH	Partial/Full[εϕ]
600580	3.5	1744	46	10.1	46	20	2020	IP	EWH	Full
Great Miami River (14-001-000)										
201922	118.5	842	56	11.2	52	25	2020	ECBP	EWH	Full
H05S05	106.1	927	50	10.3	50	29	2020	ECBP	EWH	Full
H05S19	98.97	1124	54	10.5	46	30.5	2020	ECBP	EWH	Full
H05W01	91.14	1154	56	10	52	41	2020	ECBP	EWH	Full

STORET	RM	DA	IBI	MIWB	ICI	EPT	Year	ECO	ALU	Attain
H05K01	81.8	1853	49	11	54	25	2020	ECBP	WWH	Full
H09W02	78.85	2587	52	9.9	44	20	2020	ECBP	WWH	Full
H09S13	66.9	2711	52	10.3	50	25	2020	ECBP	WWH	Full
H09W28	55.14	3117	54	10.4	56	33	2020	ECBP	WWH	Full
H09W28	55.14	3117	52	10.4	54	27	2021	ECBP	WWH	Full[Ʊ]
H09W78	51.24	3137	50	9.9	28*	3	2021	ECBP	WWH	[ε, Ʊ, ϒ]
600330	49.27	3189	54	10.1	56	29	2020	ECBP	WWH	Full
600330	49.27	3189	52	9.8	52	25	2021	ECBP	WWH	Full[Ʊ]
201886	43.6	3278	50	10.1	54	24	2021	ECBP	WWH	Full[Ʊ]
610090	43.23	3280	42	10.2	24*	7	2020	ECBP	WWH	Partial[ε]
610090	43.23	3280	48	9.2	42	18	2021	ECBP	WWH	Full[Ʊ]
H11W35	34.1	3636	50	11.8	22*	5	2020	ECBP	WWH	Partial[ε]
H11W35	34.1	3636	56	10.8	54	22	2021	ECBP	WWH	Full[Ʊ]
H11C01	24.55	3799	46	10.3	36/E	6	2020/21	IP	WWH	Full[ϕ]
H11W20	15.49	3838	40	10.4	32	8	2020	IP	WWH	Full
H11W20	15.49	3838	44	10.4	56	29	2021	IP	WWH	Full[Ʊ]
H11K14	9.5	3872	48	11	32	7	2020	IP	WWH	Full
Mad River (14-100-000)										
H04P09	17.48	527	50	10.1	54	33	2020	ECBP	WWH	Full
H04S03	8.7	616	44	9.8	50	27	2020	ECBP	WWH	Full
H04P23	0.28	657	52	9.7	56	21	2020	ECBP	WWH	Full
Stillwater River (14-200-000)										
H06P03	27.86	503	60	10.7	42	35	2020	ECBP	EWH	Full
H06P07	23.44	523	58	10.6	E	34	2020	ECBP	EWH	Full
H06P09	17.45	602	58	10.9	44	29	2020	ECBP	EWH	Full
H06S11	11.39	645	52	9.8	42	27	2020	ECBP	EWH	Full
H06W30	5.78	660	58	10.5	54	40	2020	ECBP	EWH	Full
H06K01	1.5	674	58	9.2	52	32	2020	ECBP	EWH	Full
White River (14-300-000)										
H11W65	3.8	1384	52	11.4	56	26	2020	IP	EWH	Full
Muskingum River (17-001-000)										
300146	110.7	4852	44	9.5	NA	NA	2020	WAP	WWH	Full
611740	108.28	4861	48	9.9	42	25	2020	WAP	WWH	Full
611740	108.28	4861	54	10.2	NA	NA	2021	WAP	WWH	Full
R11W03	101.8	4883	49	9.5	52	31	2020	WAP	WWH	Full
611750	92	5993	48	9.6	52	30	2020	WAP	WWH	Full
R11S12	84.7	6042	52	10.4	52	31	2020	WAP	WWH	Full
R16P06	75.67	6850	40	9.2	52	28	2020	WAP	WWH	Full
R16P08	67.48	7196	44	10.2	48	29	2020	WAP	WWH	Full
R16S28	56.4	7386	44	8.9	42	26	2020	WAP	WWH	Full
R16S39	48.81	7422	48	10.2	42	27	2020	WAP	WWH	Full
R16S06	39.3	7457	44	9.7	28*	13	2020	WAP	WWH	Partial[ǂ]
R16S20	33.5	7470	44	9.6	44	19	2020	WAP	WWH	Full
R19K07	24.8	7713	43	9.3	44	23	2020	WAP	WWH	Full
R19K05	14	7995	40	10	32	16	2020	WAP	WWH	Full
R19K02	5.7	8035	47	10	36	15	2020	WAP	WWH	Full
Killbuck Creek (17-150-000)										
R04S02	18.36	503	44	9.2	50	20	2021	WAP	WWH	Full
203603	13.28	581	40	9	54	33	2021	WAP	WWH	Full
203602	2.1	599	48	9.4	52	32	2021	WAP	WWH	Full
Licking River (17-200-000)										
601770	26.75	537	41	10.4	52	22	2020	EOLP	WWH	Full

STORET	RM	DA	IBI	MIWB	ICI	EPT	Year	ECO	ALU	Attain
601770	26.75	537	40	10.6	36	NA	2021	EOLP	WWH	Full
603300	18.87	672	43	9.9	54	30	2020	WAP	WWH	Full
R13S27	3.68	753	47	11.6	30*	16	2020	WAP	WWH	Partial[ɛ]
Sandy Creek (17-450-000)										
R07S71	0.57	504	44	10	44	14	2021	WAP	WWH	Full
Tuscarawas River (17-500-000)										
R06W79	89	518	52	9.1	36	19	2021	EOLP	WWH	Full
R06A02	78.16	574	52	9.6	50	NA	2021	WAP	WWH	Full
R06P75	73.67	586	39	8.7	36	NA	2021	WAP	WWH	Full
R10K18	63.2	1404	46	10.9	52	24	2021	WAP	WWH	Full
R10K12	52.3	1816	44	10.3	44	23	2021	WAP	WWH	Full
R10K10	44.5	2364	58	10.8	48	20	2021	WAP	EWH	Full
R10G02	38.68	2381	52	10	52	27	2021	WAP	EWH	Full
611790	21.17	2443	56	10.2	52	31	2021	WAP	EWH	Full
R10S11	15.25	2480	52	10.2	50	23	2021	WAP	EWH	Full
601840	10.73	2566	48	9.8	E	23	2021	WAP	EWH	Full
611730	0.3	2596	52	10	50	26	2021	WAP	EWH	Full
Walhonding River (17-600-000)										
601910	15.73	1505	52	10.5	54	37	2021	WAP	EWH	Full
300288	8.81	1572	33*	9.1	NA	NA	2021	WAP	EWH	Partial[ł]
R04S35	7.54	1575	52	10	50	34	2021	WAP	EWH	Full
R04W27	0.76	2255	46	9.7	50	33	2021	WAP	EWH	Full
Mohican River (17-700-000)										
300286	27	573	47	9.8	52	28	2021	EOLP	EWH	Full
601870	16.92	948	45	9.7	48	37	2021	WAP	EWH	Full
304208	11.8	966	40*	8.3*	NA	NA	2020	WAP	EWH	Non
200636	11.5	967	54	10.7	NA	NA	2020	WAP	EWH	Full
300284	6.53	987.7	40*	8.6*	48	30	2021	WAP	EWH	Partial[ł]
200634	0.45	998	39*	8.2*	48	30	2021	WAP	EWH	Partial[ł]
Wills Creek (17-800-000)										
R18S01	46.57	659	30*	7.5*	46	17	2021	WAP	WWH	Partial[ɛ]
R18S22	37.74	672	36	9.2	44	21	2021	WAP	WWH	Full
302624	18.54	770.5	29*	8.3	36	14	2021	WAP	WWH	Partial[ɛ]
611770	7.04	842	42	9.6	46	17	2021	WAP	WWH	Full
Mahoning River (18-001-000)										
N03K31	36.2	606	48	9.5	42	19	2021	EOLP	WWH	Full
N03S56	26.36	880	40	9.7	42	17	2021	EOLP	WWH	Full
N03W21	17.63	1017	42	8.1*	32	10	2021	EOLP	WWH	Partial[ɛ]
602300	12.42	1074	46	9.3	38	7	2021	EOLP	WWH	Full
N03S51	11.43	1075	50	8.8	NA	NA	2021	EOLP	WWH	Full
Cuyahoga River (19-001-000)										
F01S13	24.1	555	38	8.5	48	20	2021	EOLP	WWH	Full
F01S11	15.61	698	42	9.4	48	22	2021	EOLP	WWH	Full
F01S09	9.7	744	38	8.9	40	19	2021	EOLP	WWH	Full

ɛ – Impaired/Threatened condition is consistent with prior biological and water quality surveys. Reports are available at: ***https://epa.ohio.gov/divisions-and-offices/surface-water/reports-data/biological-and-water-quality-reports***

ł – Impaired condition new or additional

ƒ – The macroinvertebrate community score does not factor in assessments of impounded segments.

ʊ – Sites included in the 2021 follow up sampling.

ʏ – Site located in a mixing zone.

φ-Macroinvertebrate sample from 2021

Water Chemistry – Historic Perspective and Trends

Water chemistry data for large rivers collected from 1981 through 2021 were summarized using principal components analysis (PCA). Individual water chemistry observations were log10 transformed and averaged within sites and years prior to analysis. Also note that water chemistry parameters with greater than ~ 33 percent missingness were excluded from analysis[6]. PCA is typically used as a method for reducing the dimensionality of a large data set, but it is also handy for simply visualizing underlying relationships within a data set, as is the case here. For example, in Figure 6, individual sampling locations are plotted according to their respective component scores for the first two axes, and color-coded as to the timespan of years sampled. The component scores themselves are determined by the water chemistry values for a given site. Figure 6 also shows how the various water chemistry parameters relate to the axes (e.g., magnesium [mg] relates mostly to PCA 2; total dissolved solids [tds] relates to both PCA 1 and PCA 2; brackets indicate abbreviations used in the Figure).

What is visually striking in Figure 6 is the horizontal separation along the first axis (PCA 1), with sites sampled between 1981 and 1987 arrayed toward the right, coincidental with water chemistry parameters representing reduced nitrogen and heavy metals. Conversely, sites sampled from 2003 to the present are on the left of PCA 1, positioned away from heavy metals and reduced nitrogen. Also apparent is the temporal sequence going from right to left, reflecting the improvements in water quality first associated with the construction grants program that funded improvements to public wastewater infrastructure, and subsequently through on-going efforts, including the implementation of agricultural best management practices (BMPs) aimed at reducing soil erosion. On this latter point, notice that total suspended solids [tss] and total phosphorus [tp] are oriented almost identically in Figure 6, and again, positioned toward the right-hand side. PCA 2 represents hardness and alkalinity, and a tendency toward naturally higher productivity in alkaline streams. The chemistry variable [pChl] is a proxy for chlorophyll given by the residuals from a regression of total suspended solids on iron.

Figure 7 plots the third component (PCA 3) on the first component (PCA 1). PCA 3 represents a counter gradient of temperature and dissolved oxygen, with warmer temperatures oriented in a positive direction along the PCA 3 (i.e., the y-axis), and lower dissolved oxygen concentrations oriented, intuitively, in a negative direction. What is apparent is that there is a significant progression toward warmer temperatures through time. Arsenic [as], chloride [cl] and total Kjeldahl nitrogen [tkn] also align with PCA 3, and trend up through time (after a significant initial decrease for TKN relative to 1981-1987). Whether the trend in TKN is related to warmer temperatures (and increased precipitation) is an open question, but was investigated by looking at TKN from the ambient stations where flow and temperature data exist, as will be described in the next section. Lastly, the fourth component (PCA 4; Figure 8) represents a productivity gradient that is orthogonal to PCA 2 and is more likely a gradient induced by cultural eutrophication than the natural gradient (associated with alkalinity) represented by PCA 2.

[6] Aluminum, alkalinity, potassium, sodium, and sulfate. For parameters with less than 33 percent missingness, values were imputed using the missMDA package in R.

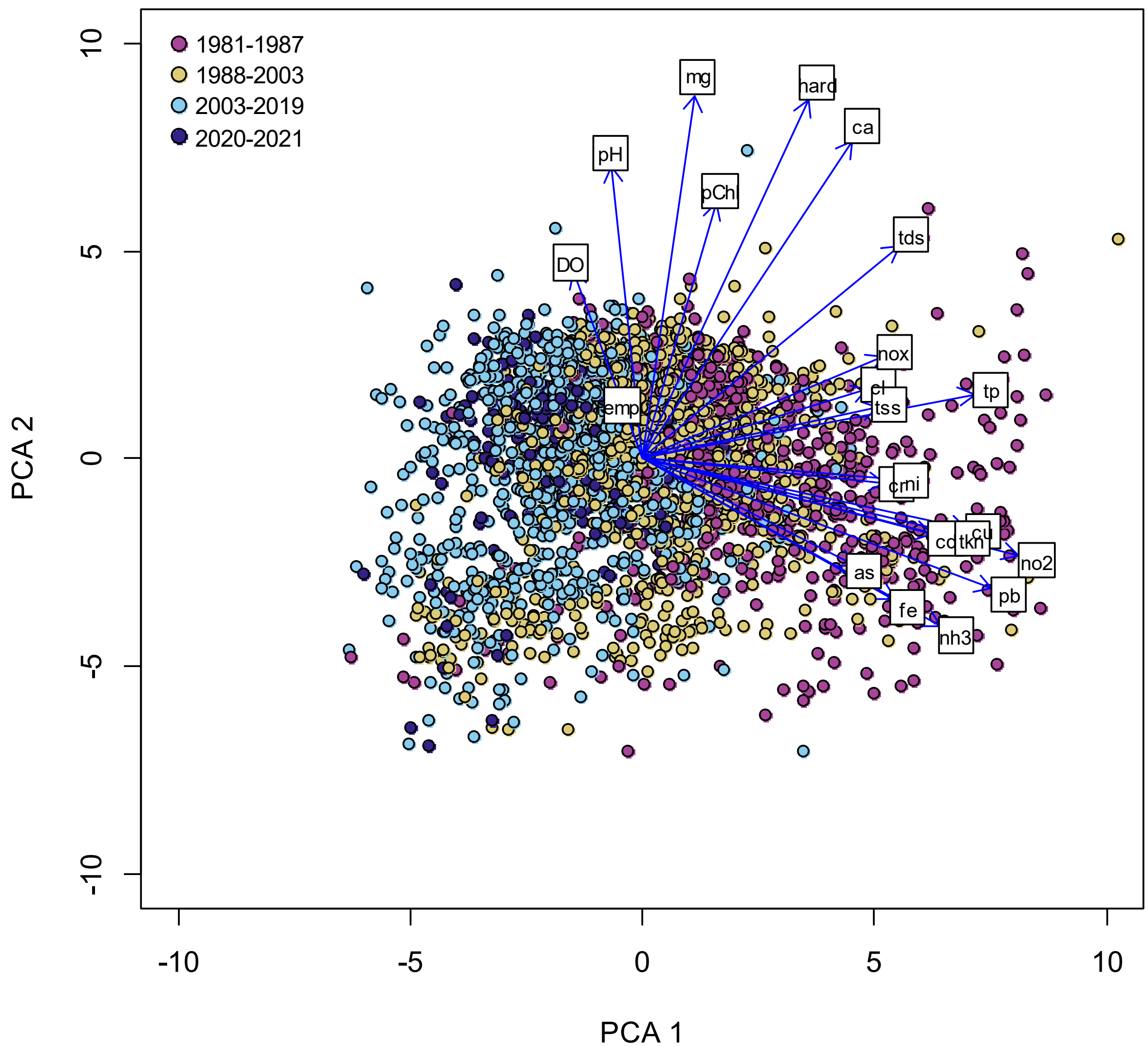


Figure 4 - A biplot showing the first two axes from a principal components analysis (PCA) of water chemistry data collected from large rivers in Ohio, 1981-2021.

The first axis accounts for 27.3 percent of the variance in the data set, and the second axis accounts for 18.9 percent. The vectors leading to individual parameters show the degree of association with the respective axes, and the length of the arrow shows the relative amount of correlation. Points in the plot are individual sampling locations positioned by their component scores.

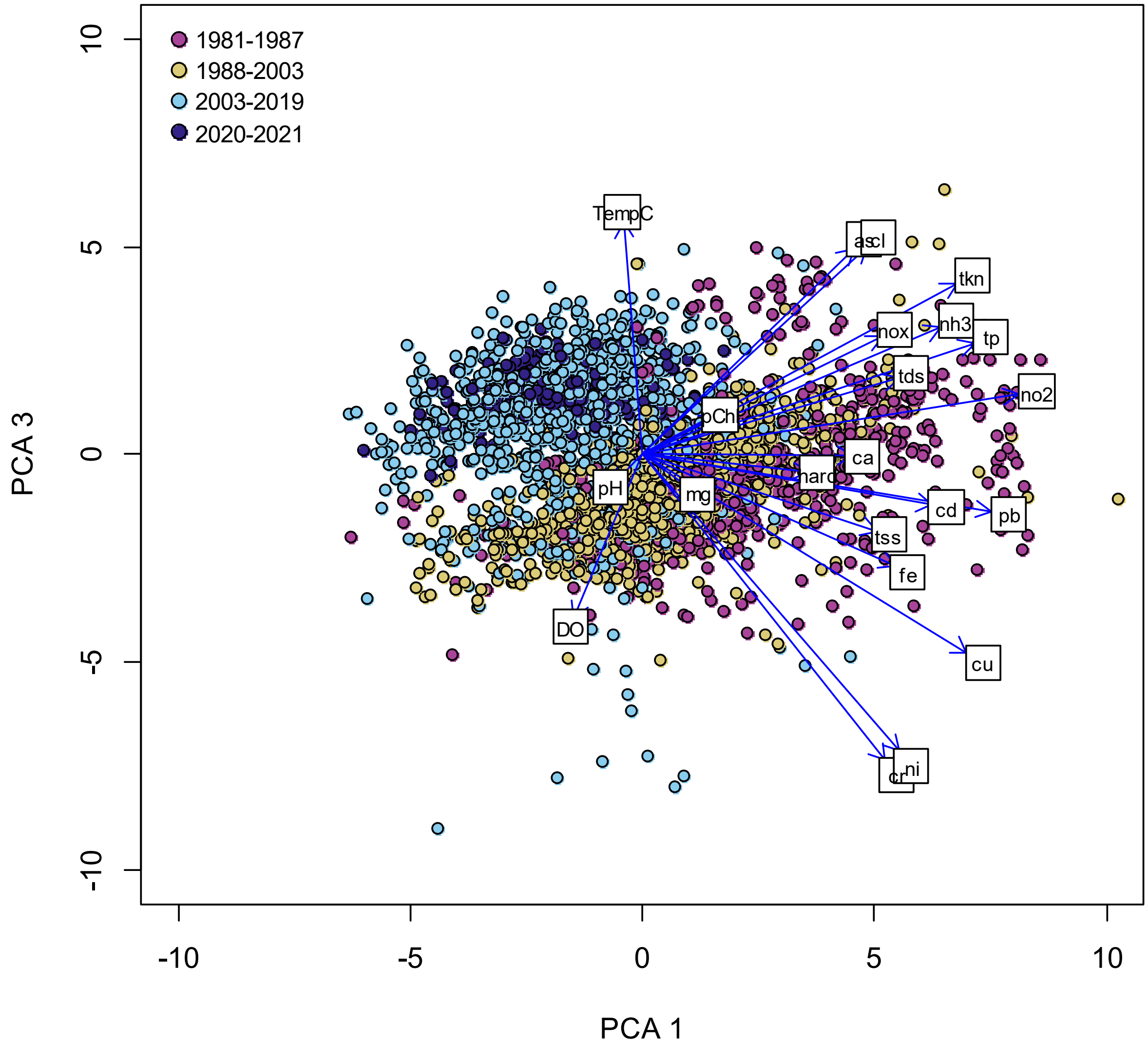


Figure 5 - A biplot showing the first and third axes from a principal components analysis (PCA) of water chemistry data collected from large rivers in Ohio, 1981-2021.

The third axis accounts for 13.0 percent of the variance in the dataset.

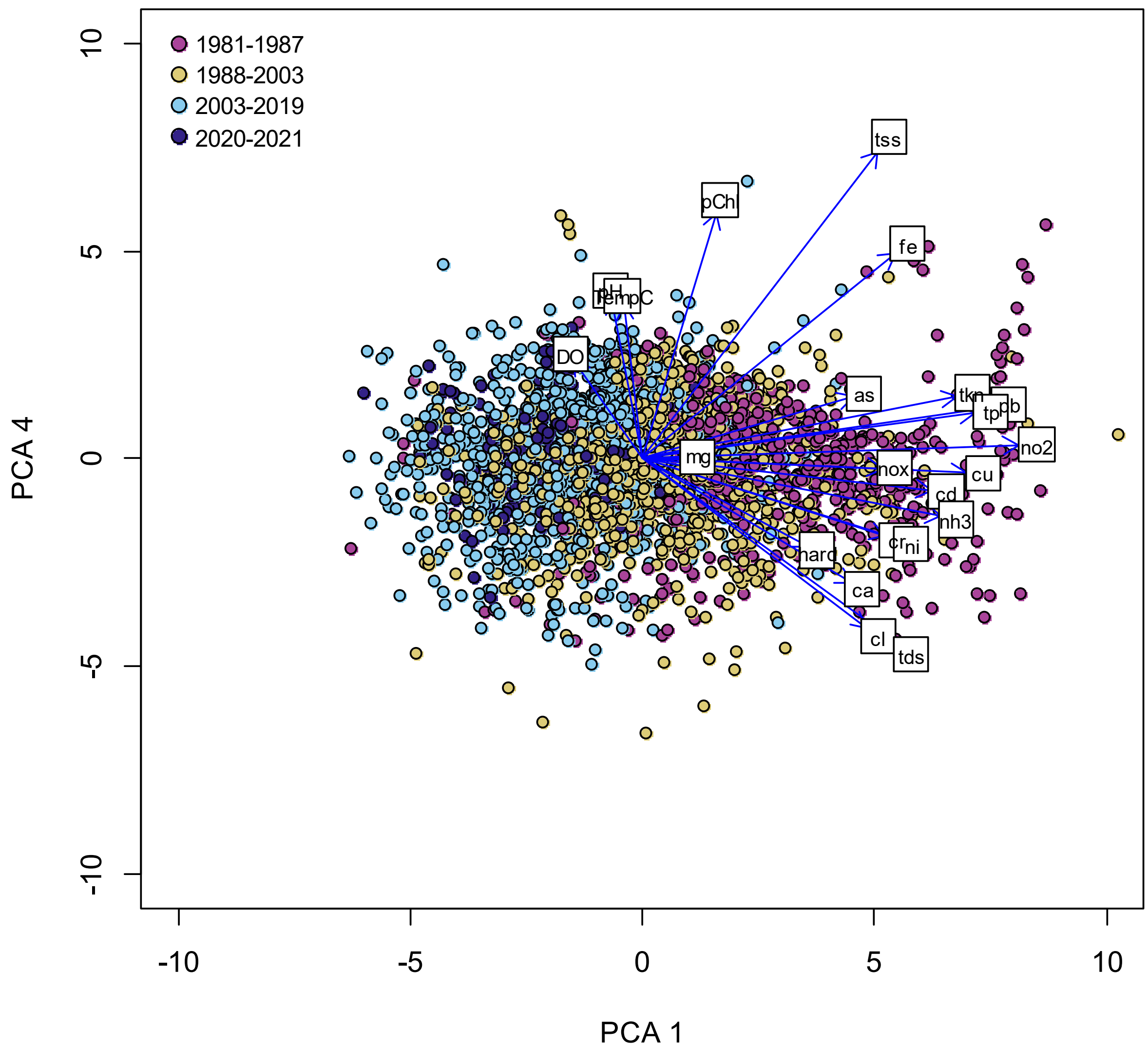


Figure 6 - A biplot showing the first and fourth axes from a principal components analysis (PCA) of water chemistry data collected from large rivers in Ohio, 1981-2021.

The fourth axis accounts for 9.8 percent of the variance in the dataset.

Trends for Individual Parameters

The boxplots in Figure 9 show gross trends in selected water chemistry variables over the stated time periods (the same periods as shown in Figures 6-8). The letters arrayed along the top of each plot indicate similar means as given by the emmeans package in R; models were formulated as general additive models using the mgcv package where river was considered a random effect: e.g., Pb ~ ERA + *s*(RIVERCODE, bs="re"). The dramatic decline in lead and ammonia concentrations between the 1981-1987 and 1988-2002 timeframes obviously coincides with wastewater infrastructure improvements afforded by the Construction Grants[7] program. The trend for lead may also be linked to the phase-out of leaded gasoline. And lead may also serve as a proxy for other heavy metals used in industrial applications such as cadmium, copper, and zinc. The adoption of agricultural BMPs aimed at reducing soil erosion accelerated starting in 2003 (Miltner 2015), and stormwater BMPs to address urban and suburban sources were increasingly adopted over that time frame (internal Ohio EPA communications). The additive effect these additional actions had on improved water quality is evident first in the decrease in total suspended solids (TSS) observed between the 1988-2002 and 2003-2019 periods, and in the successive decrease in total phosphorus concentrations over the first three time intervals. For total phosphorus, the initial decrease can be attributed to the construction grants/state revolving loan program, and the second decrease is due to a combination of agricultural BMPs and tighter phosphorus limits at publicly owned treatment works (POTWs). A continued and encouraging decline in suspended solids observed during the 2020-2021 survey likely reflects continued purging of legacy sediments stored in the river channel (Meals et al. 2010).

Water temperatures show a distinct upward trend by sequentially increasing across timeframes, with the temperatures from the 2020-2021 survey being decidedly higher than previous frames. These warmer temperatures were coincidental with lower dissolved oxygen levels (based on a linear contrast of the 2020-2021 period against the other three), and increased TKN and organic nitrogen concentrations. The increase in TKN did not coincide with an increase in ammonia nitrogen (a component of TKN) suggesting that sewage or recent manure applications were not the source. Increasing concentrations of riverine organic nitrogen have been linked to increasing temperature and discharge (Deininger et al. 2020). To gain insight into whether the observed increase in organic N was related to discharge, temperature or both, concentrations observed at ambient stations on a given day were matched to stream discharge at accompanying USGS gage stations. Four competing linear mixed effects models were formulated using the lme4 package in R and compared via ANOVA. The four models were:

$$N_{org} \sim Y + T + Q + (1|\text{Station})$$

$$N_{org} \sim Y + Q{:}\text{Station} + (1|\text{Station})$$

$$N_{org} \sim T + Q{:}\text{Station} + (1|\text{Station})$$

$$N_{org} \sim Y + T + Q{:}\text{Station} + (1|\text{Station})$$

Where Y is year, T is stream temperature, Q is discharge, Q:Station is an interaction term for discharge by station, and (1|Station) is the random effect of station.

The ANOVA comparison suggested that the fourth model has the best fit, but the first model is the most parsimonious. In either model the respective slopes for temperature and year are similar. The model results indicate that temperature captures significant variation not accounted for by discharge, and that organic N generally increases with discharge; the one exception being the Hocking River (Table 3).

[7] https://www.epa.gov/enviro/igms-construction-grants-overview

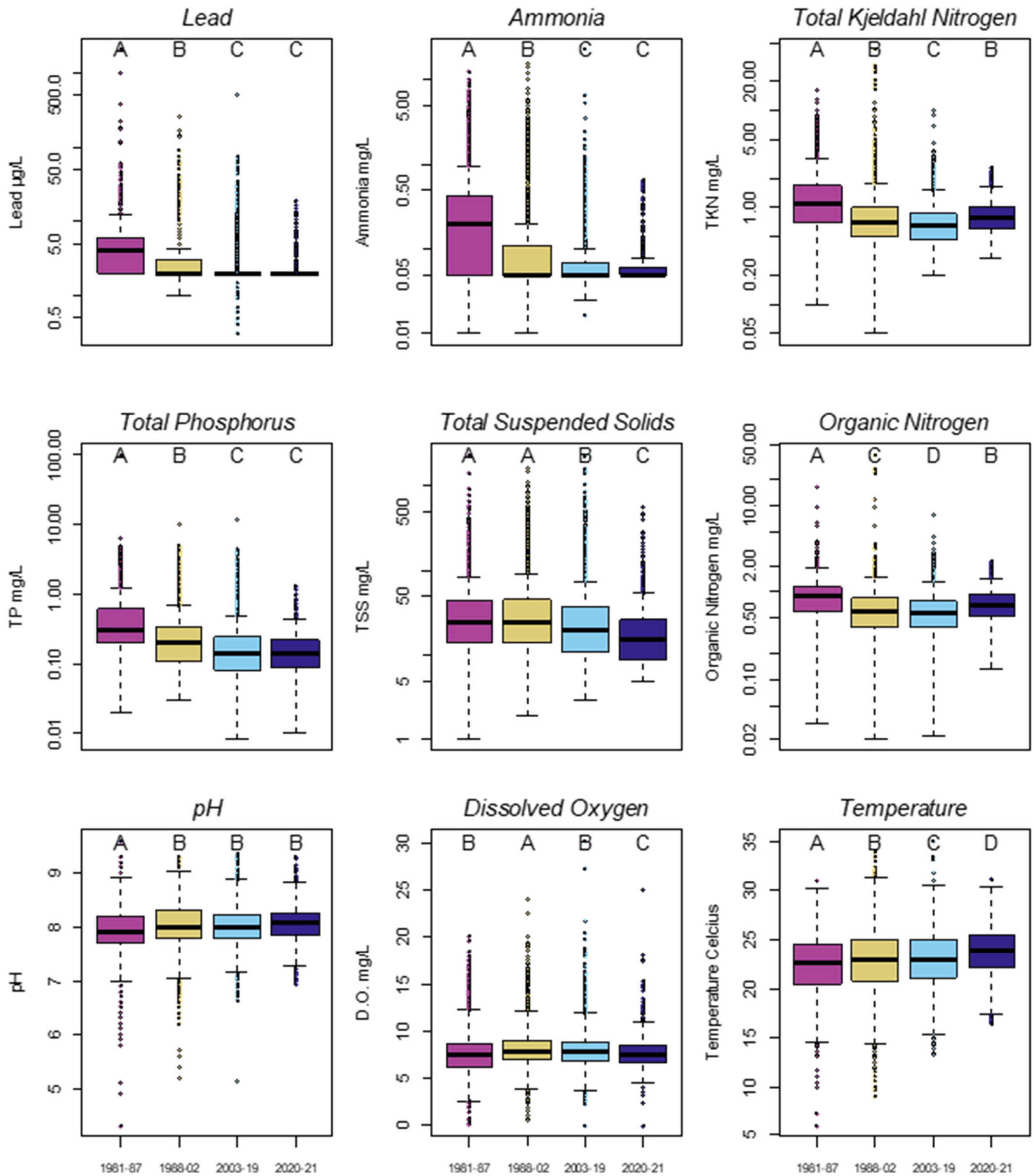


Figure 7 - Distributions of selected water quality parameters by environmentally relevant time periods.

Distributions (with a given parameter) sharing a common letter are statistically similar. General linear models were fit assuming a gamma distribution for lead, ammonia, TKN, total phosphorus, TSS, and organic nitrogen. A gaussian distribution was assumed for pH, dissolved oxygen, and temperature. The package emmeans was used to obtain estimated marginal means at the 95 percent confidence level. Note that the temperature data excludes the month of October. Temperature data include the months of June, July, August and September.

Table 2 - Variable importance on the principal components.

The relative contribution of a given parameter to a listed dimension is indicated by the value in the respective columns. Large values indicate that a given parameter contributed more to a given dimension (e.g., Dim.1 or the first dimension represents reduced nitrogen).

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5
As	3.44	1.59	8.50	1.04	0.42
Ca	3.39	14.00	0.00	4.17	3.90
Cd	6.46	0.80	0.52	0.26	1.05
Chloride	3.88	0.68	8.68	7.63	3.31
Cr	4.53	0.09	18.86	1.62	3.77
Cu	8.11	0.67	7.91	0.05	7.26
DO	0.37	4.85	5.39	2.65	15.05
Fe	4.91	2.77	2.52	11.32	12.00
Hardness	2.13	17.91	0.06	2.04	3.32
Mg	0.21	18.30	0.29	0.00	2.15
NH3	6.86	3.93	3.27	0.90	0.31
Ni	5.05	0.06	17.69	1.77	6.07
NO2	10.88	1.30	0.72	0.05	0.94
NO3+NO2	4.44	1.43	2.81	0.02	2.56
Pb	9.39	2.33	0.65	0.73	4.14
pH	0.07	11.81	0.20	6.94	8.53
TDS	5.06	6.31	1.20	9.24	0.12
TempC	0.03	0.36	10.82	6.41	11.17
TKN	7.61	0.80	5.91	1.06	6.92
TP	8.50	0.58	2.52	0.55	0.44
TSS	4.25	0.36	1.17	25.33	6.09
pChl	0.42	9.06	0.30	16.22	0.46

Table 3 - Comparisons of linear mixed effects models examine the relationship between organic nitrogen, stream discharge and temperature.

The Bayesian Information Criterion (BIC) score suggests that Model 1 is the most parsimonious (obviously lacking an interaction term). The Akaike Information Criterion (AIC) and log-likelihood score suggest Model 4 has the best fit to the data.

Model	Terms	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
1	6	-152.85	-121.043	82.427	-164.85			
2	21	-155.83	-44.489	98.914	-197.83	32.9733	15	0.004734
3	21	-156.04	-44.701	99.019	-198.04	0.2116	0	
4	22	-170.75	-54.112	107.376	-214.75	16.7128	1	4.349e-05

Fixed Effects

	Estimate	Std. Error	t value
(Intercept)	-7.1268040	2.3688655	-3.009
Year	0.0048024	0.0011773	4.079
Temperature	0.0031425	0.0007784	4.037
Q x Maumee (Waterville)	0.0285055	0.0286727	0.994
Q x Sandusky	0.1102658	0.0340925	3.234
Q x Cuyahoga	-0.0065663	0.0610711	-0.108
Q x Grand	0.0738662	0.0437385	1.689
Q x St. Joe	0.1658530	0.0360221	4.604
Q x Scioto	-0.0191871	0.0399175	-0.481
Q x Olentangy	0.0715553	0.0425072	1.683
Q x Big Darby	0.1461219	0.0368849	3.962
Q x Licking	0.0153989	0.0455968	0.338
Q x L. Beaver	0.0600203	0.0584479	1.027
Q x Mahoning (Leavittsburg)	0.1127431	0.0599382	1.881
Q x Mahoning (Lowellville)	0.0496090	0.0650277	0.763
Q x Stillwater	0.1573490	0.0403929	3.895
Q x Hocking	-0.1201946	0.0391761	-3.068
Q x Maumee (Independence)	0.0368429	0.0320613	1.149
Q x Portage	0.0258816	0.0378777	0.683
Q x Paint	0.1295989	0.0320790	4.040

Water Chemistry - Present Status

To evaluate overall patterns in water chemistry for the 2020-2021 survey, principal components analysis (PCA) was performed. The PCA found dimensions formed by a gradient of alkalinity (27.7 percent of the variance in the data; Figure 10), pollution (16.0 percent of the variance; parameters loading on this dimension include copper, nickel, zinc, total phosphorus, dissolved phosphorus, and total Kjeldahl nitrogen; Figure 11), eutrophication (10.5 percent of the variance; parameters include 5-day biological oxygen demand, chlorophyll a, dissolved oxygen saturation, pH, and temperature; Figure 12), and a manganese and sulfate dimension (7.5 percent) that is essentially orthogonal to the alkalinity gradient.

Sites with water chemistry results loading high on the pollution dimension (Table 4) were primarily from the Muskingum River basin, including the Muskingum River mainstem, Tuscarawas River, and Killbuck Creek. One site from the Scioto River (immediately downstream from the Little Scioto River) and one from the Cuyahoga River also had results loading high on the pollution dimension. In all cases except for the Scioto River site (V02W23; RM 175.75), the samples were collected during high flow events, and therefore not typical of ambient conditions.

Sites on the eutrophication dimension were primarily from the Maumee, Auglaize, and Scioto Rivers (Table 5). Multiple sites from the lower Scioto River were hypertrophic as characterized by sestonic chlorophyll concentrations greater than 100 ug/L and BOD5 greater than 6 mg/L. Results from the Auglaize River (P06S10, RM 14.94) were similarly consistent with hypertrophy. Results from one site on the Grand River were included because of a high percent dissolved oxygen saturation value. This result appears anomalous in light of other available data (i.e., low levels of sestonic and benthic chlorophyll, and 5-day BOD less than detection).

Dissolved oxygen and pH results from automated data loggers, as well as benthic chlorophyll collections, also inform which sites are symptomatic of eutrophication. Benthic and sestonic chlorophyll together account for 20 percent of the variation in 24-hour dissolved oxygen range, with benthic chlorophyll accounting for eight percent. Sites with relatively high levels of benthic chlorophyll also tended to have high pH and elevated BOD5 (Table 5). Eutrophication based on these measures appears especially pronounced in the lower Scioto River downstream from Circleville to its confluence with the Ohio River, the Maumee River downstream from Napoleon to Lake Erie, and the lower Great Miami River downstream from Dayton to the Ohio River.

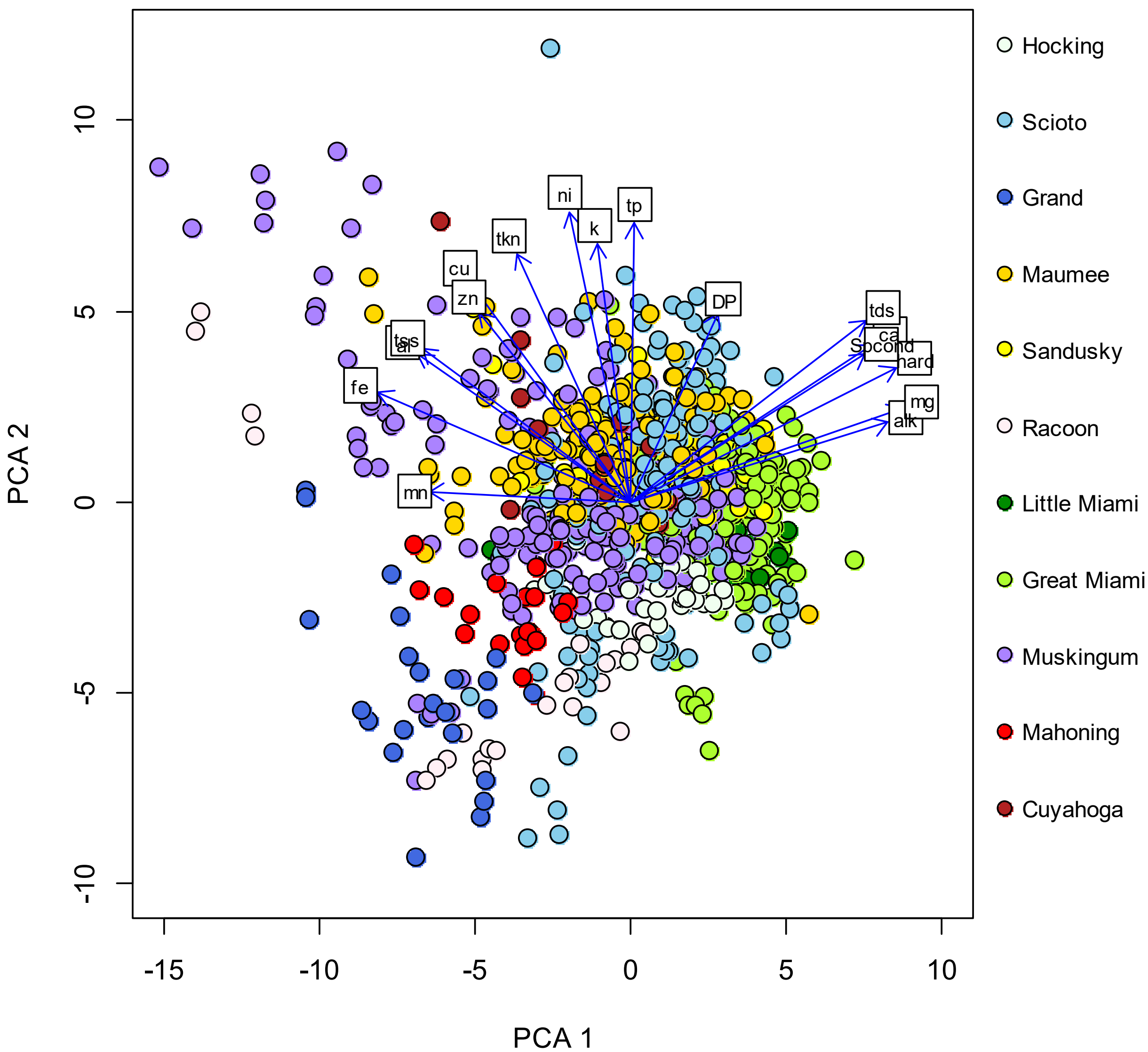


Figure 8 - Site scores for the first two principal components color-coded by basin.

The loadings of individual parameters on the axes are indicated as vectors.

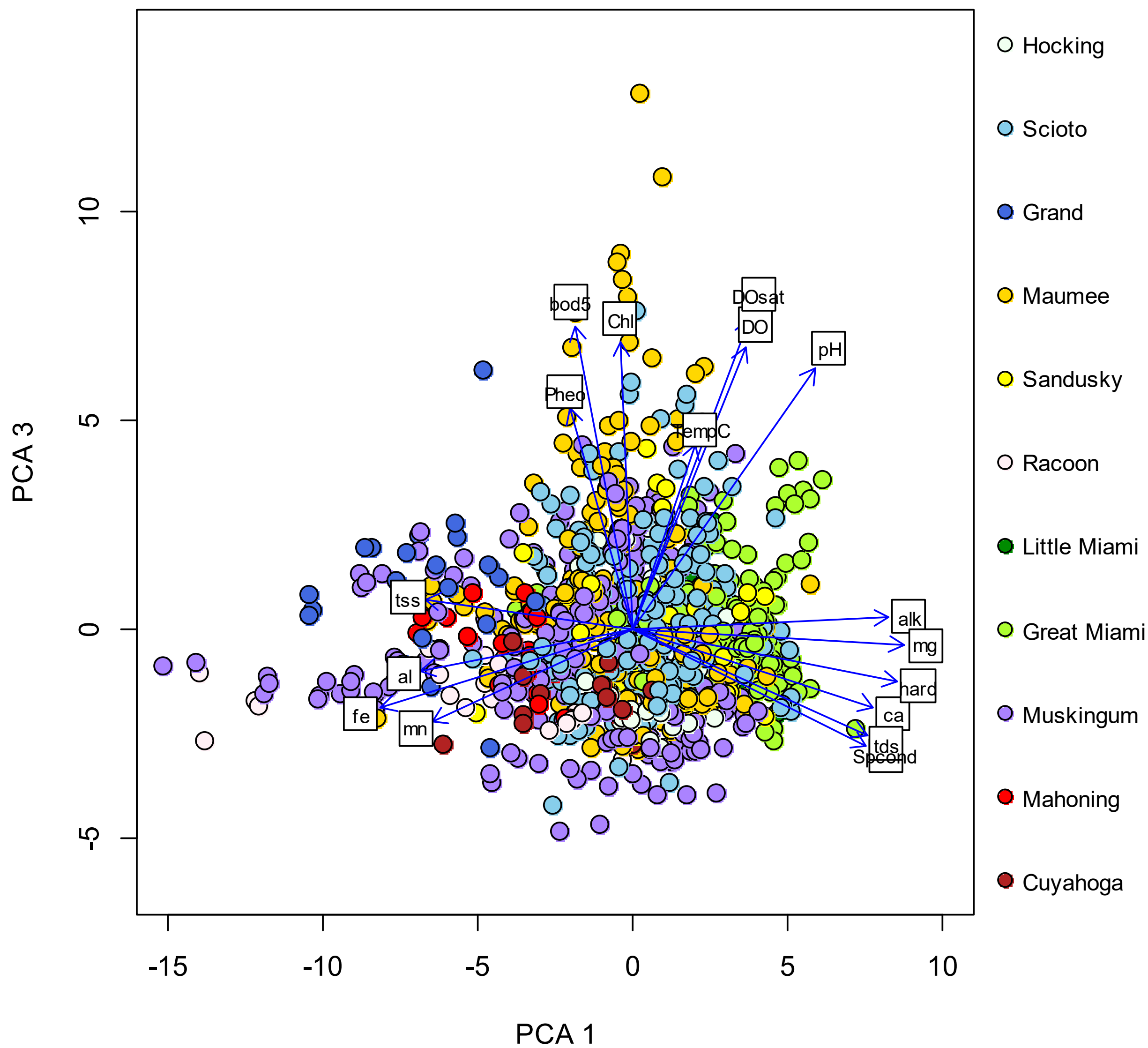


Figure 9 - Site scores for the first and third principal components color-coded by basin.

The loadings of individual parameters on the axes are indicated as vectors.

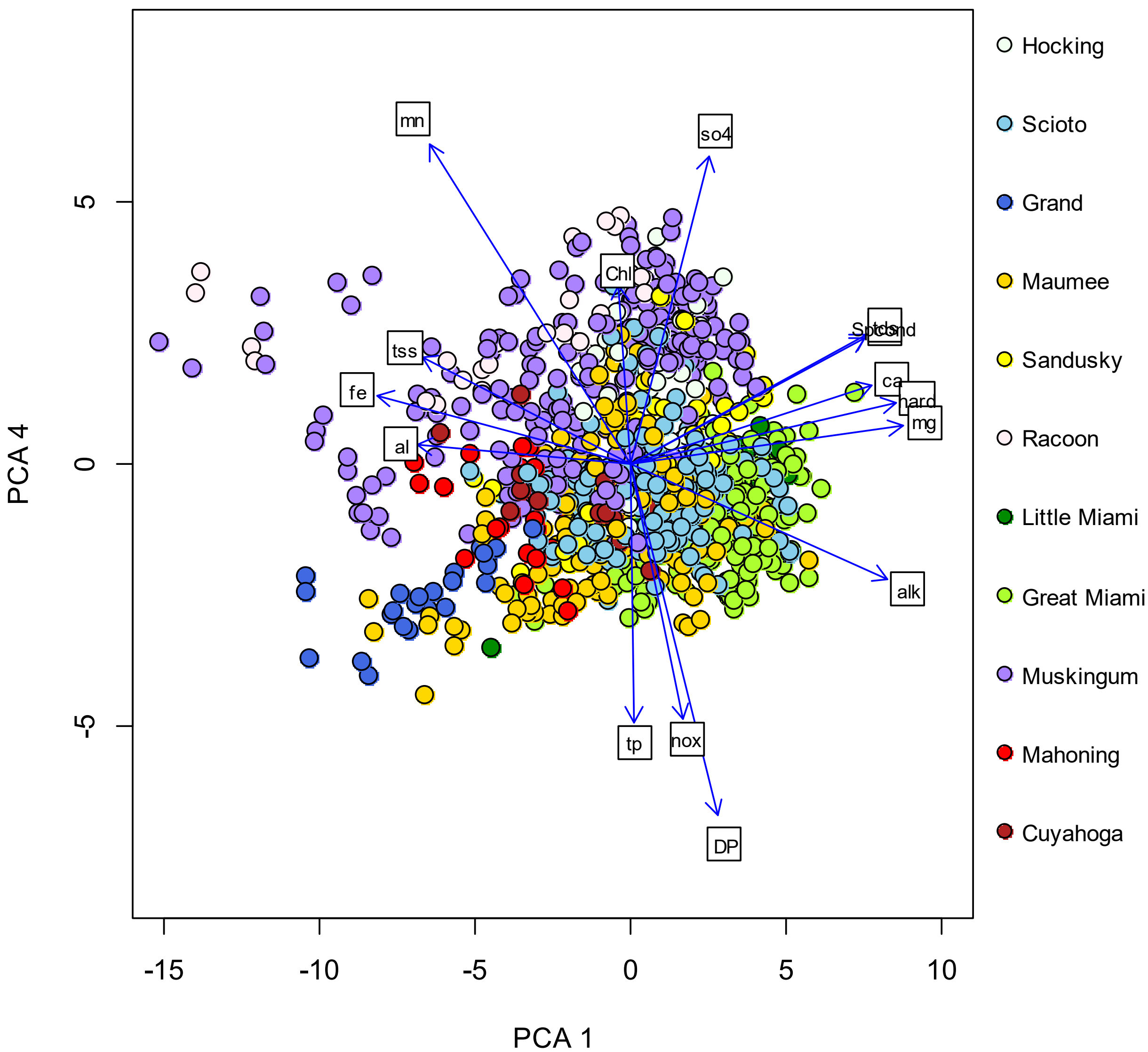


Figure 10 - Site scores for the first and fourth principal components color-coded by basin.

The loadings of individual parameters on the axes are indicated as vectors.

Table 4 - Stations with chemistry results loading high on the pollution dimension.

Upper percentiles for the 2020-2021 survey data are shown for reference. The sample collected from the Scioto River (V02W23; RM 175.75) was done during base flow, the other nine samples were collected under high flows.

SHEET	STORET	RIVERCODE	RM	TKN	TP	Ni	Cu
119992	V02W23	02-001-000	175.8	2.45	1.32	18.8	4.8
117719	611740	17-001-000	108.3	1.75	0.48	11.7	9.8
117723	R11S12	17-001-000	84.7	1.26	0.38	10.8	9.5
117724	R11W03	17-001-000	101.8	1.48	0.36	10.9	9.0
118514	601840	17-500-000	10.73	1.54	0.45	13.3	11.5
118516	611730	17-500-000	0.3	1.50	0.47	11.2	9.7
118518	611790	17-500-000	21.17	1.97	0.53	11.5	10.0
119932	203603	17-150-000	13.28	2.42	0.83	21.6	16.6
119933	R04S02	17-150-000	18.36	2.00	0.62	18.0	14.5
120067	F01S09	19-001-000	9.7	1.51	0.42	9.8	9.1
			90th	1.25	0.31	5.3	4.4
			95th	1.49	0.39	6.4	5.1
			98th	1.81	0.51	8.4	6.7

Table 5 - Sites with chemistry results symptomatic of excessive eutrophication.

Values in bold red font indicate the potential for materially degrading biological assemblages or contributing to or causing impairment (Miltner 2018). The first half of the table lists sites aligned with the eutrophication axis represented in Figure 12. The second half lists sites identified as eutrophic by results from automated data loggers and benthic chlorophyll levels. The cutoff for including sites with high levels of benthic chlorophyll was 223 mg/m2 (the 90th percentile of the set). The cutoff for 24-h DO range was 7 mg/L.

Sites Loading on Dimension 3 [Eutrophic] - Individual Results								
				Chlorophyll				
SHEET	STORET	River	RM	Sestonic Chlorophyll	Pheophytin Chlorophyll	pH	DOsat	BOD5
119526	600940	Scioto	86.4	**121**	9.85	8.76	127	5.35
119524	301543	Scioto	78.8	98.4	34.6	8.8	125	**6.5**
119525	600770	Scioto	56.17	**124**	84.9	8.29	106	**6.36**
119523	201807	Scioto	40	**163**	92.6	8.69	120	**7.95**
119522	201805	Scioto	33	**186**	101	8.54	112	**8.37**
118956	201805	Scioto	33	**132**	11.1	8.58	84.8	4.49
119529	V15P15	Scioto	24.5	**244**	66.7	8.89	147	**11**
119528	V15K02	Scioto	14.67	**230**	107	8.7	137	**11.6**
119576	V10W12	Paint	1.2	**61.3**	6.85	7.96	79.1	**6.02**
119051	G02S13	Grand	6.1	5.83	4.31	**9.13**	154	1
119016	P09P02	Maumee	44.35	92.4	21.9	8.9	**185**	5.43
119018	P11K31	Maumee	26.7	**54.7**	47.9	**9.04**	132	**6.54**
119019	500080	Maumee	20.68	**58.3**	44.1	**9.3**	**202**	**7.29**
119167	500080	Maumee	20.68	**97**	38.5	**9.07**	**187**	**6.73**
119020	301740	Maumee	16.52	**48.6**	46.3	**9.27**	**155**	**6.65**

119168	301740	Maumee	16.52	**77.1**	46.9	**9.02**	**160**	**6.45**
119035	301644	Maumee	13.3			8.78	**222**	
120079	301644	Maumee	13.3			8.94	**157.7**	
118923	P06S10	Auglaize	14.94	6.77	1.43	8.73	229	4.56
118981	P06S10	Auglaize	14.94	**146**	58.2	8.7	**309**	**10.4**
119570	P06S10	Auglaize	14.94	**76.8**	16.2	8.51	**222**	**6.96**
119941	P06S10	Auglaize	14.94	**147**	58	8.81	**174**	**8.6**
120212	P06S10	Auglaize	14.94	**68.3**	7	9.07		**9.26**
117319	R19K05	Muskingum	14	**121**	15.9	8.23	84.6	3.44
118436	601910	Walhonding	15.73	**107**	10	8.37	96.7	4.68
Eutrophic Sites Identified by Automated Data Logger and Benthic Chlorophyll Results									
				Chlorophyll		Sonde		Mean BOD5
Year	STORET	River	RM	Sestonic	Benthic	pH	DO Range	
2021	201807	Scioto	40	15.3	77.7	8.71	**7.11**	**2.6**
2021	201805	Scioto	33	15.1		8.8	**8.71**	**2.6**
2021	V15P15	Scioto	24.5	24.8		8.82	**10.33**	3.5
2021	V15W01	Scioto	5	7		8.83	**7.18**	**3.4**
2021	P09P02	Maumee	44.35	13.6	99.6	8.72	**8.74**	**4.4**
2021	301740	Maumee	16.52	11.2	123	8.99	**7.59**	**4.3**
2021	P06S10	Auglaize	14.94	9.8		8.01	**7.53**	**5.5**
2021	P05S03	Blanchard	35.24	1.1	88.9	8.66	**9.78**	1.1
2021	U04Q06	Sandusky	23	6.8	77.4	8.79	**11.99**	2
2020	H05S05	Great Miami	106.1	7.33	257	8.59	4.96	1.1
2020	H09W02	Great Miami	78.85	1.6	461	8.47	**10.8**	1.1
2020	H09S13	Great Miami	66.9	1.2	333	8.71	**9.66**	1.1
2020	H09W28	Great Miami	55.14	2.7	266	8.48	5.17	1
2021	H09W78	Great Miami	51.24	4.3	231	8.36	2.37	1.7
2020	201886	Great Miami	43.6	7.2	394	8.85	**10.09**	1
2020	610090	Great Miami	43.23	4.3		8.83	**10.98**	1.6
2020	H11W35	Great Miami	34.1	2.5	535	8.63	3.91	2.1
2021	H11C01	Great Miami	24.55	5.8	115.5	8.78	**9.38**	1.8
2020	H11C01	Great Miami	24.55	5	471.5	8.7	7.82	2.6
2021	H11W20	Great Miami	15.49	8.2	78.9	8.78	**10.45**	1.6
2020	H11W20	Great Miami	15.49	3.5	208.5	8.89	**8.08**	**2.6**
2020	H11K14	Great Miami	9.5	5.8	256	8.96	6.52	3.7
2020	H04P09	Mad	17.48	6.35	634	8.39	3.92	1.6
2021	200634	Mohican	0.45	7.3	232	8.61	4.49	2.7

Organic Chemistry

Organic compounds were detected in 32 of 142 water column samples. There were 43 total detections out of a possible 13,944 individual analyses for a detection frequency of 0.31 percent. For comparison, the detection frequency in organic samples collected from large rivers between 1999 and 2019 is 2.51 percent. Most of the detections were either for heptachlor epoxide, a pesticide degradate of heptachlor, or for hexachlorobenzene in the Tuscarawas River. General use of heptachlor was banned in 1988, and most of the detections of heptachlor epoxide were near the reporting limit. A major source of hexachlorobenzene to the Tuscarawas River is PPG in Barberton. Detections of hexachlorobenzene were generally an order of magnitude higher than the reporting limit and exceeded the Ohio River human health criterion of 0.0077 µg/L. The plasticizer butyl benzyl phthalate was detected in the Great Miami River and Muskingum River, and in all cases at concentrations slightly higher than the reporting limit. Halogenated methane compounds were detected in the Great Miami River in trace concentrations, and in the Muskingum River at concentrations two orders of magnitude above reporting limits.

Table 6 - Detections of organic compounds in water quality samples collected during the 2020-2021 large rivers survey.

All concentrations are in µg/L. Values listed in the percentile column show the percentile rank for the listed concentration relative to all large river samples collected between 1999 and 2021. Given an overall detection frequency of 2.5 percent, any detection is likely to have a high percentile rank, but comparing the difference between the concentration and the reporting limit to the percentile rank provides relative sense for how far a concentration is above the detection limit.

Sheet	RM	PARAMETER	Concentration	Reporting Limit	Percentile
Scioto					
120000	56.17	Heptachlor epoxide	0.0036	0.0020	0.953
Grand					
119417	40.1	Heptachlor epoxide	0.0022	0.0020	0.908
119413	22.46	Heptachlor epoxide	0.0021	0.0020	0.903
119370	22.46	Methoxychlor	0.0132	0.0101	0.990
119418	6.1	Heptachlor epoxide	0.0022	0.0020	0.908
Great Miami					
117846	66.9	Butyl benzyl phthalate	2.1600	2.0200	0.992
117839	49.27	BHC-alpha	0.0031	0.0020	0.946
117822	49.27	Chloroform	0.6660	0.5000	0.898
117822	49.27	Trihalomethanes	0.6660	0.5000	0.408
Muskingum					
117725	101.8	Butyl benzyl phthalate	2.5300	2.0200	0.995
117722	92	Butyl benzyl phthalate	2.5200	2.0200	0.995
117727	75.67	Butyl benzyl phthalate	3.8000	2.0200	0.999
119808	74.07	Chlorodibromomethane	5.1500	0.5000	0.999
119808	74.07	Chloroform	15.6000	0.5000	0.998
119808	74.07	Dichlorobromomethane	11.4000	0.5000	1.000
119808	74.07	Methyl chloride	22.5000	0.5000	0.998
119808	74.07	Trihalomethanes	32.1000	0.5000	0.896
Tuscarawas					
118467	89	Hexachlorobenzene	0.0557	0.0061	0.984
118351	89	Hexachlorobenzene	0.1180	0.0061	0.990
118466	81.46	Hexachlorobenzene	0.0431	0.0061	0.981
118350	81.46	Hexachlorobenzene	0.0461	0.0061	0.982
118349	71.73	Hexachlorobenzene	0.0145	0.0061	0.964
118465	71.73	Hexachlorobenzene	0.0104	0.0061	0.957

Sheet	RM	PARAMETER	Concentration	Reporting Limit	Percentile
118471	63.2	Heptachlor epoxide	0.0040	0.0020	0.960
118471	63.2	Hexachlorobenzene	0.0266	0.0061	0.974
118355	63.2	Hexachlorobenzene	0.0140	0.0061	0.963
118464	51.11	Heptachlor epoxide	0.0044	0.0020	0.965
118464	51.11	Hexachlorobenzene	0.0375	0.0061	0.979
118348	51.11	Hexachlorobenzene	0.0113	0.0061	0.959
118470	44.5	Heptachlor epoxide	0.0040	0.0020	0.960
118470	44.5	Hexachlorobenzene	0.0191	0.0061	0.969
118469	38.68	Heptachlor epoxide	0.0041	0.0020	0.961
118353	38.68	Hexachlorobenzene	0.0094	0.0061	0.954
118469	38.68	Hexachlorobenzene	0.0287	0.0061	0.975
118472	30.9	Heptachlor epoxide	0.0041	0.0020	0.961
118472	30.9	Hexachlorobenzene	0.0299	0.0061	0.976
118519	21.17	Heptachlor epoxide	0.0040	0.0020	0.960
118519	21.17	Hexachlorobenzene	0.0369	0.0061	0.979
119862	0.3	Hexachlorobenzene	0.0141	0.0061	0.963
Mahoning					
118324	17.63	Heptachlor epoxide	0.0032	0.0020	0.944
118321	12.42	Heptachlor epoxide	0.0024	0.0020	0.918
Cuyahoga					
119416	24.1	Heptachlor epoxide	0.0029	0.0020	0.936
119414	9.7	Heptachlor epoxide	0.0027	0.0020	0.930

Sediment Chemistry - Organics

Sediment samples were collected at 76 of the large river survey locations (Figure 13). Detections of organic compounds in sediments were rare, accounting for 1.7 percent of all 10,157 analytical scans. Relatively high levels of polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were present in the Mahoning River. Lower levels of PAHs were detected near or downstream from urban areas in the Licking River, Olentangy River, Scioto River, and Great Miami River. All detections of PAHs normalized for total organic carbon were below probable effect levels (PEL) listed in McDonald et al. 2000. Note that comparing carbon normalized values is a more conservative (i.e., more likely to exceed) approach than comparing raw values to the benchmarks. Total PCBs were above the PEL at all sites in the Mahoning River and most of the Tuscarawas River (Figure 13 and Table 7). Hexachlorobenzene contaminated the sediments in the Tuscarawas River and the entire Muskingum River mainstem. Hexachlorobenzene is water insoluble but lipophilic and bioaccumulative; therefore, sediment contamination is the primary route for exposure to the food chain. The range of values reported from the Tuscarawas River was 29 to 1,300 µg/kg (normalized to TOC, the range is 1,193 – 59,954 µg/kg). For comparison[8], values reported from the industrialized Rhine and Elbe rivers in Germany range from 10 to 5,100 µg/kg. In terms of the potential to directly impact benthic invertebrates via toxic effects, the concentrations observed in the Tuscarawas River may potentially pose a risk, given that the lowest effect level for TOC normalized concentrations suggested for sediment guidelines developed for Ontario (Jaagumagi 1993, Persaud et al. 1993) is 20 µg/kg, and the severe effect level is 2,400 µg/kg.

Detection frequency of organic compounds was lower in 2020-2021 compared to 2002-2019 and 1972-2001. The rate of detections across the three time frames is 1.7 percent, 6.1 percent, and 8.3 percent (for 2020-2021, 2002-2019, and 1972-2001, respectively). For several parameters with significant detections

[8] The world beater is 280,000 µg/kg measured downstream from the Dow Chemical outfall to the St. Claire River in 1985.

in the 2020-2021 survey, comparisons of distributions to the aforementioned timeframes demonstrate an overall decreasing trend in concentrations, especially for PAHs where the concentrations have decreased by two orders of magnitude on average relative to the 1972-2001 timeframe (Figure 14). Concentrations of PCB-1254 were slightly but significantly higher in 2020-2021 compared to 2002-2019. There were 31 common stations sampled between those two time periods. In the 2002-2019 timeframe, three stations had PCB-1254 concentrations above detection, but those same stations in 2020-2021 had undetectable levels. In the 2020-2021 timeframe, nine of those 31 stations had detectable levels. For all stations where detections occurred regardless of the time period, the average concentrations were slightly, but not significantly higher in 2020-2021. Given the ubiquity of PCBs in the environment, and the dynamic nature of sediments in rivers, the apparent increase in the 2020-2021 timeframe may have simply been luck of the draw.

Sediment Chemistry - Metals

Concentrations of metals in sediment samples collected during the 2020-2021 Large Rivers survey broadly reflected parent lithology, with higher concentrations of calcium and magnesium found in the western half of the state compared to the eastern half. Otherwise, concentrations reflected industrial and mining legacies with elevated heavy metal concentrations in Mahoning and Tuscarawas River sediment samples, two locations from the Scioto River, one location on the Blanchard River downstream from Findlay, and the one location sampled on Sandy Creek (Figure 15 and Table 9). Based on sediment screening levels suggested by Ohio EPA (2010), none of the samples exceed the Tier III level.

Sediment metal concentrations have generally trended downward relative to 1972-2002 (Figure 16). Concentrations for Cd, Cr, Cu, Hg, Ni, Pb, Zn and Mn were compared[9] for three time periods: 1972-2002, 2003-2019, and 2020-2021. In all cases except for manganese, concentrations measured in 2020-2021 were significantly lower than in the initial timeframe, and lower compared to 2003-2019, but not significantly (at the 95 percent CI level). In the case of manganese, concentrations were lower in 2003-2019 compared to 1972-2002, but the concentrations in 2020-2021 were similar to 1972-2002. Whether the uptick in manganese is related to increasing temperature is an open question, but one worth monitoring.

[9] Based on a generalized linear model using a gamma distribution and means comparison using the emmeans package

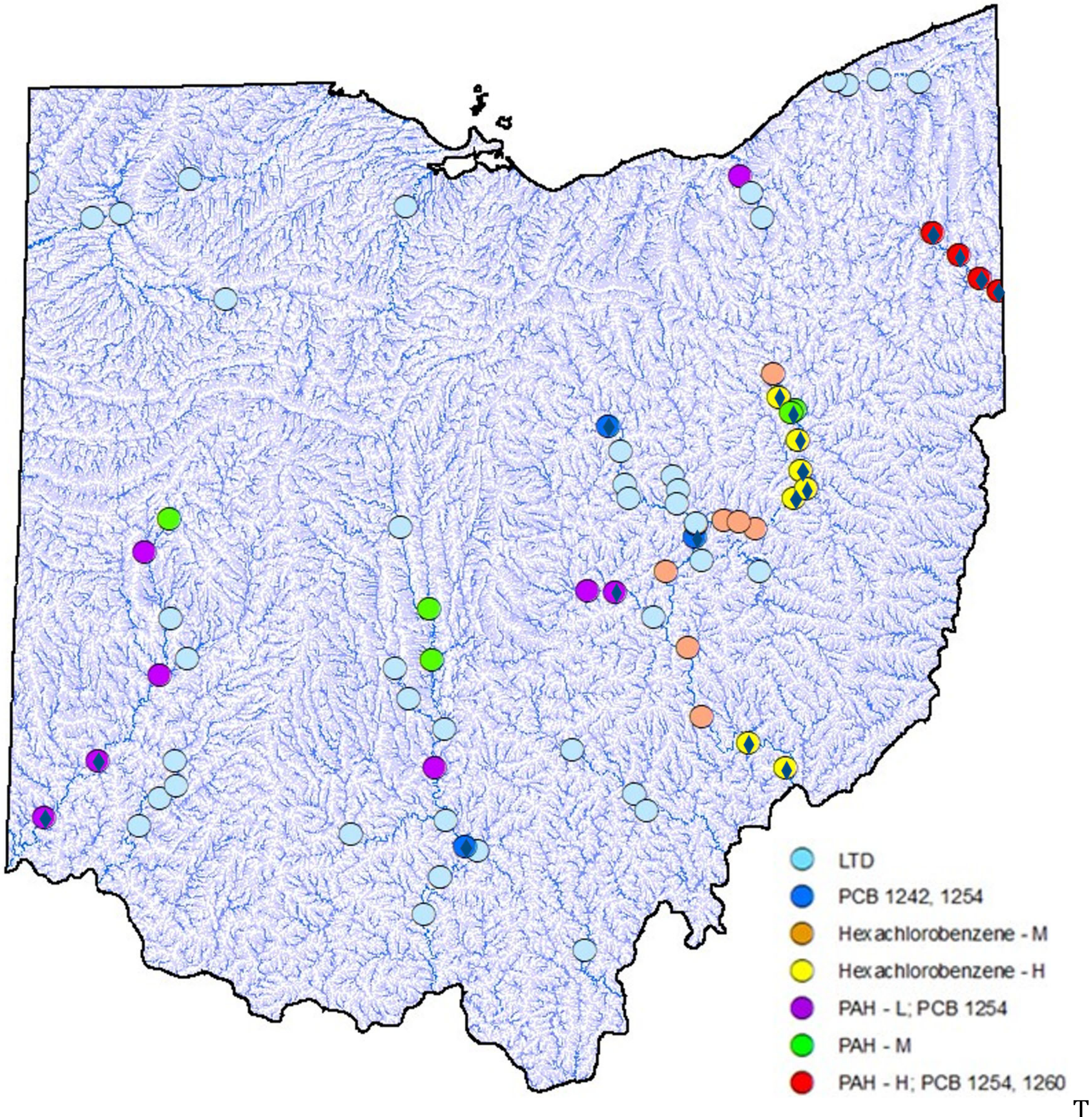


Figure 11 - Locations of sediment samples collected during the 2020-2021 large rivers survey.

Points are color-coded based on level of similarity. LTD refers to points where most or all of the 107 organic analytes were at less than analytical reporting limits. All other points had concentrations significantly above detection levels. The legend labels indicate the parameters with significant detections associated with the color group. The codes H, M, L indicate relative magnitude of concentrations (higher, medium and lower). Sites with blue diamond symbols superimposed had total PCB concentrations in excess of the probable effect level given in MacDonald et al. 2000.

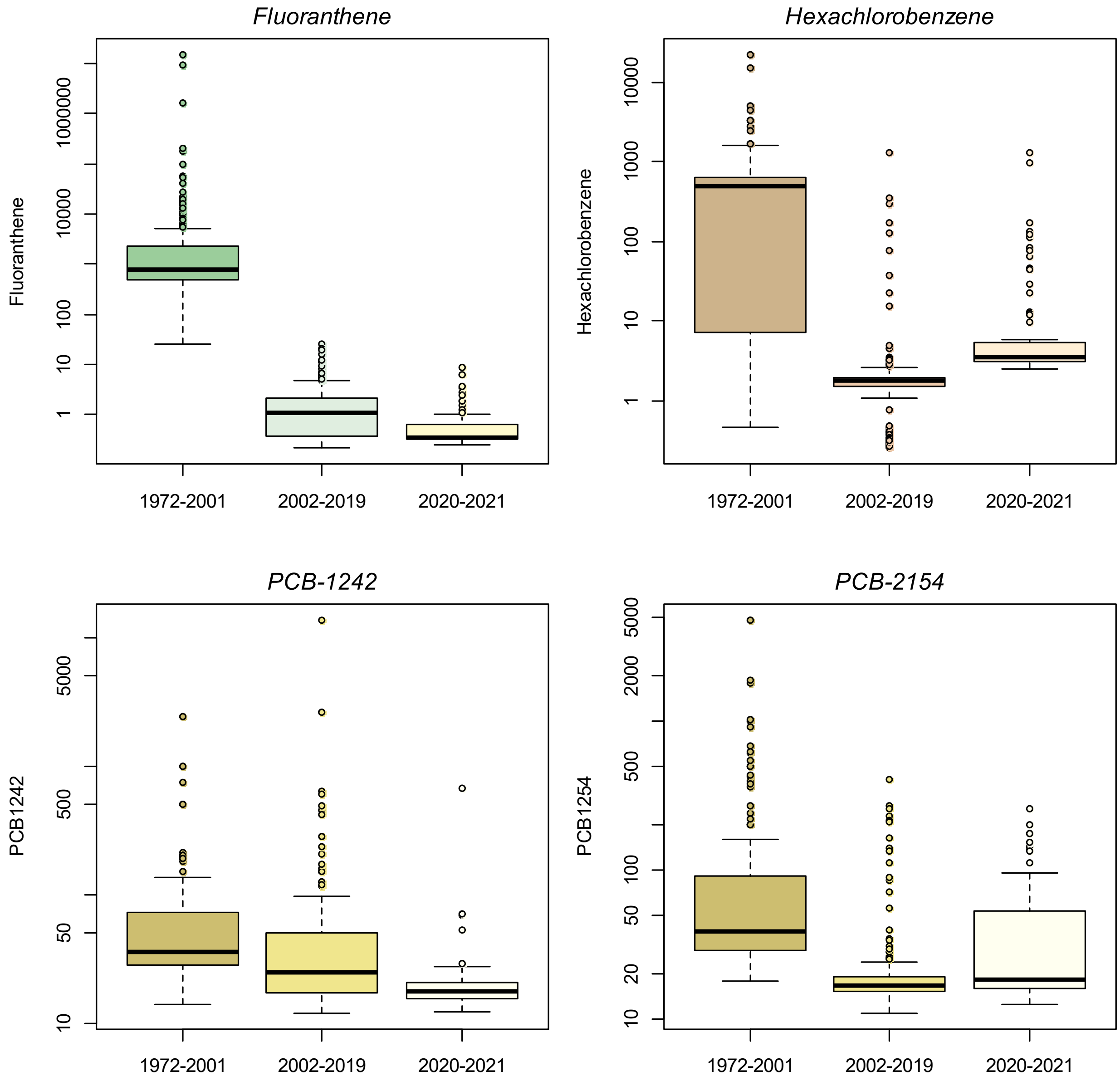


Figure 12 - Distributions of concentrations exceeding reporting limits for selected sediment organic parameters within three timeframes.

All concentrations are in µg/kg. Note that detection limits for hexachlorobenzene were higher in 2020-2021 than 2002-2019.

Table 7 - Summary of sediment chemistry results from the 2020-2021 large rivers survey.

Scans indicate the number of sediment samples where the listed parameter was analyzed. Freq is the frequency of detections above reporting or detection limits for the given number of scans. Min and Max are minimum and maximum values reported for the given parameter. Note that the minimum values are the minimum detection limits; where the detection frequency is zero, the minimum and maximum values represent the range of detection limits. Station information is given for the maximum reported value (above the detection limit) for a listed parameter. %TOC is the total organic carbon fraction associated with the maximum respective parameter value. Concentrations are in units of µg/kg.

PARAMETER	Scans	Freq	Min	Max	%TOC	STORET	STATION
4,4'-DDD	87	0.011	4.95	21.1	3.12	R10K18	TUSCARAWAS R. @ POWER LINES DST. DOVER DAM
4,4'-DDT	87	0.034	4.95	13.5	1.39	F01S13	CUYAHOGA R. AT JAITE @ HIGHLAND RD.
4,4-DDE	83	0.060	4.95	13.7	1.39	F01S13	CUYAHOGA R. AT JAITE @ HIGHLAND RD.
bis(2-Ethylhexyl)phthalate	100	0.010	2.47	5.86	0.53	611770	WILLS CREEK @ TWP. RD. 274 (USGS GAGE)
d-BHC	87	0.011	4.95	29.9	1.98	M05S12	L. MIAMI R. NEAR FORT ANCIENT @ ST. RT. 350
Hexachlorobenzene	104	0.163	4.95	1300	2.17	R06W79	TUSCARAWAS R. 0.13 MI. UPST. MASSILLON WWTP
PCB-1242	74	0.054	24.7	681	1.96	600770	SCIOTO R. DST. CHILLICOTHE @ HIGBY BRIDGE
PCB-1254	74	0.297	25	258	4.73	N03S56	MAHONING R. AT GIRARD, DST. LIBERTY ST. DAM
PCB-1260	74	0.081	24.7	615	4.92	N03W13	MAHONING R. AT WARREN @ MAIN ST.
Anthracene	100	0.020	0.495	1.67	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Benzo(a)anthracene	99	0.081	0.495	4.12	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Benzo(a)pyrene	97	0.113	0.495	4.34	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Benzo[b]fluoranthene	95	0.137	0.495	3.99	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Benzo[g,h,i]perylene	99	0.081	0.495	2.47	7.67	V04S16	OLENTANGY R. AT FOOTBRIDGE AT O.S.U.
Benzo[k]fluoranthene	98	0.092	0.495	3.54	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Chrysene	97	0.113	0.495	4.52	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Fluoranthene	93	0.215	0.495	8.85	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Indeno[1,2,3-cd]pyrene	98	0.102	0.495	2.87	7.67	V04S16	OLENTANGY R. AT FOOTBRIDGE AT O.S.U.
Naphthalene	100	0.010	0.495	6.57	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Phenanthrene	98	0.102	0.495	4.42	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
Pyrene	95	0.147	0.495	6.96	4.67	602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.
1,4-Naphthoquinone	141	0.000	0.495	1.17	3.47		
2-Methylnaphthalene	100	0.000	0.495	1.17	3.47		
3-Methylcholanthrene	100	0.000	0.495	1.17	3.47		
Acenaphthene	100	0.000	0.495	1.17	3.47		
Acenaphthylene	100	0.000	0.495	1.17	3.47		
Dibenz[a,h]anthracene	100	0.000	0.495	1.17	3.47		
Dibenzofuran	100	0.000	0.495	1.17	3.47		
Fluorene	100	0.000	0.495	1.17	3.47		
1,2,4,5-Tetrachlorobenzene	100	0.000	0.495	1.17	3.47		
1,2,4-Trichlorobenzene	100	0.000	0.495	1.17	3.47		
1,3-Dinitrobenzene	100	0.000	2.47	5.86	0.53		
2,3,4,6-Tetrachlorophenol	82	0.000	2.47	5.86	0.53		
2,4,5-Trichlorophenol	82	0.000	0.495	1.17	3.47		
2,4,6-Trichlorophenol	82	0.000	2.47	5.86	0.53		
2,4-Dichlorophenol	82	0.000	2.47	5.86	0.53		
2,4-Dimethylphenol	82	0.000	2.47	5.86	0.53		
2,4-Dinitrophenol	82	0.000	2.47	5.86	0.53		
2,4-Dinitrotoluene	100	0.000	0.495	1.17	3.47		
2,6-Dichlorophenol	82	0.000	2.47	5.86	0.53		
2,6-Dinitrotoluene	100	0.000	0.495	1.17	3.47		
2-Acetylaminofluorene	100	0.000	0.495	1.17	3.47		

PARAMETER	Scans	Freq	Min	Max	%TOC	STORET	STATION
2-Chloronaphthalene	100	0.000	0.495	1.17	3.47		
2-Chlorophenol	82	0.000	2.47	5.86	0.53		
2-Methylphenol	82	0.000	0.495	1.17	3.47		
2-Nitroaniline	100	0.000	0.495	1.17	3.47		
2-Nitrophenol	82	0.000	2.47	5.86	0.53		
2-Picoline	120	0.000	0.495	5.52	2.59		
3,3'-Dichlorobenzidine	100	0.000	0.495	1.17	3.47		
3-,4-methylphenol	82	0.000	2.47	5.86	0.53		
4,6-Dinitro-2-methylphenol	82	0.000	2.47	5.86	0.53		
4-Bromophenyl-phenylether	100	0.000	0.495	1.17	3.47		
4-Chloro-3-methylphenol	82	0.000	6.19	14.6	3.47		
4-Chlorophenyl-phenylether	100	0.000	0.495	1.17	3.47		
4-Nitroaniline	100	0.000	0.495	1.17	3.47		
4-Nitrophenol	82	0.000	2.47	5.86	0.53		
7,12-Dimethylbenz[a]anthracene	126	0.000	0.495	1.17	3.47		
a-BHC	84	0.000	4.95	11.7	3.47		
Acetophenone	100	0.000	0.495	1.17	3.47		
Aldrin	84	0.000	4.95	11.7	3.47		
Aniline	129	0.000	0.495	1.17	3.47		
b-BHC	84	0.000	4.95	11.7	3.47		
Benzyl Alcohol	100	0.000	0.495	1.17	3.47		
bis(2-Chloroethoxy)methane	100	0.000	0.495	1.17	3.47		
bis(2-Chloroethyl)ether	100	0.000	0.495	1.17	3.47		
bis(2-Chloroisopropyl)ether	100	0.000	0.495	1.17	3.47		
Butylbenzylphthalate	100	0.000	0.495	1.17	3.47		
Dieldrin	84	0.000	4.95	11.7	3.47		
Diethylphthalate	100	0.000	0.495	1.17	3.47		
Dimethylphthalate	100	0.000	0.495	1.17	3.47		
Di-n-butylphthalate	100	0.000	0.495	1.17	3.47		
Di-n-octylphthalate	100	0.000	2.47	5.86	0.53		
Diphenylamine	100	0.000	0.495	1.17	3.47		
Endosulfan I	84	0.000	4.95	11.7	3.47		
Endosulfan II	84	0.000	4.95	11.7	3.47		
Endosulfan sulfate	101	0.000	4.95	11.7	3.47		
Endrin	84	0.000	4.95	11.7	3.47		
Endrin aldehyde	109	0.000	4.95	11.7	3.47		
Ethyl methanesulfonate	100	0.000	0.495	1.17	3.47		
Heptachlor	84	0.000	4.95	11.7	3.47		
Heptachlor epoxide	88	0.000	4.95	11.7	3.47		
Hexachlorobutadiene	100	0.000	0.495	1.17	3.47		
Hexachlorocyclopentadiene	129	0.000	2.47	5.86	0.53		
Hexachloroethane	100	0.000	0.495	1.17	3.47		
Hexachloropropene	111	0.000	0.495	1.17	3.47		
Isophorone	100	0.000	0.495	1.17	3.47		
Methoxychlor	85	0.000	4.95	11.7	3.47		
Methyl methanesulfonate	129	0.000	0.495	5.52	2.59		
Mirex	84	0.000	4.95	11.7	3.47		
Nitrobenzene	100	0.000	0.495	1.17	3.47		

PARAMETER	Scans	Freq	Min	Max	%TOC	STORET	STATION
N-Nitroso-di-n-butylamine	100	0.000	0.495	1.17	3.47		
N-Nitroso-di-n-propylamine	100	0.000	0.495	1.17	3.47		
N-Nitrosomorpholine	100	0.000	0.495	1.17	3.47		
N-Nitrosopiperidine	100	0.000	0.495	1.17	3.47		
N-Nitrosopyrrolidine	100	0.000	0.495	1.17	3.47		
PCB-1016	74	0.000	24.7	58.7	3.47		
PCB-1221	74	0.000	24.7	58.7	3.47		
PCB-1232	74	0.000	24.7	58.7	3.47		
PCB-1248	74	0.000	24.7	58.7	3.47		
p-Dimethylaminoazobenzene	103	0.000	0.495	1.17	3.47		
Pentachlorobenzene	100	0.000	0.495	1.17	3.47		
Pentachlorophenol	82	0.000	2.47	5.86	0.53		
Phenacetin	100	0.000	0.495	1.17	3.47		
Phenol	82	0.000	2.47	5.86	0.53		
Pronamide	100	0.000	2.47	5.86	0.53		
Safrole	99	0.000	0.495	1.17	3.47		
y-BHC	84	0.000	4.95	11.7	3.47		

Table 8 - Stations with total PCB concentrations exceeding threshold effect levels listed in MacDonald et al. 2000.

CHEMSHEET	STORET	RM	STATION	PCB ug/kg
120057	600770	56.17	SCIOTO R. DST. CHILLICOTHE @ HIGBY BRIDGE	818
117949	600330	49.27	GREAT MIAMI R. NEAR MIDDLETOWN @ ST. RT. 73	63.9
117931	H11C01	24.55	GREAT MIAMI R. DST FERNALD, 1.0 MI DST. DRY RUN	71.6
117915	611740	108.28	MUSKINGUM R. DST. COSHOCTON @ ST. RT. 83	246.9
117921	R19K07	24.8	MUSKINGUM R. DST. BEVERLY DAM, UPST. WOLF CREEK	73.1
117919	R19K02	5.7	MUSKINGUM R. DST. DEVOLA DAM	203
117953	603300	18.87	LICKING R. AT TOBOSO @ TOBOSO RD.	64.6
119684	R07S71	0.57	SANDY CREEK E OF BOLIVAR, JUST DST. BOLIVAR DAM	72.9
120166	R06P81	81.46	TUSCARAWAS R. SE OF NAVARRE @ RIVERLAND AVE.	175
120170	R10K18	63.2	TUSCARAWAS R. NE OF DOVER @ POWER LINES DST. DOVER DAM	96.4
120172	611710	51.11	TUSCARAWAS R. NEAR SCHOENBRUNN @ CO. RD. 125	113
120174	R10K10	44.5	TUSCARAWAS R. AT TUSCARAWAS @ CO. RD. 62	144
120126	R10G02	38.68	TUSCARAWAS R. UPST. GNADENHUTTEN WWTP	70.3
120218	300286	27	MOHICAN R. ADJ. WALLY RD. (ASHLAND CR 3175)	109.1
120295	N03W13	37.43	MAHONING R. AT WARREN @ MAIN ST.	768
120293	N03S56	26.36	MAHONING R. AT GIRARD, DST. LIBERTY ST. DAM	669.2
120297	N03W21	17.63	MAHONING R. AT CAMPBELL, NEAR RR	317
120291	602300	12.42	MAHONING R. AT LOWELLVILLE @ FIRST ST.	242.3

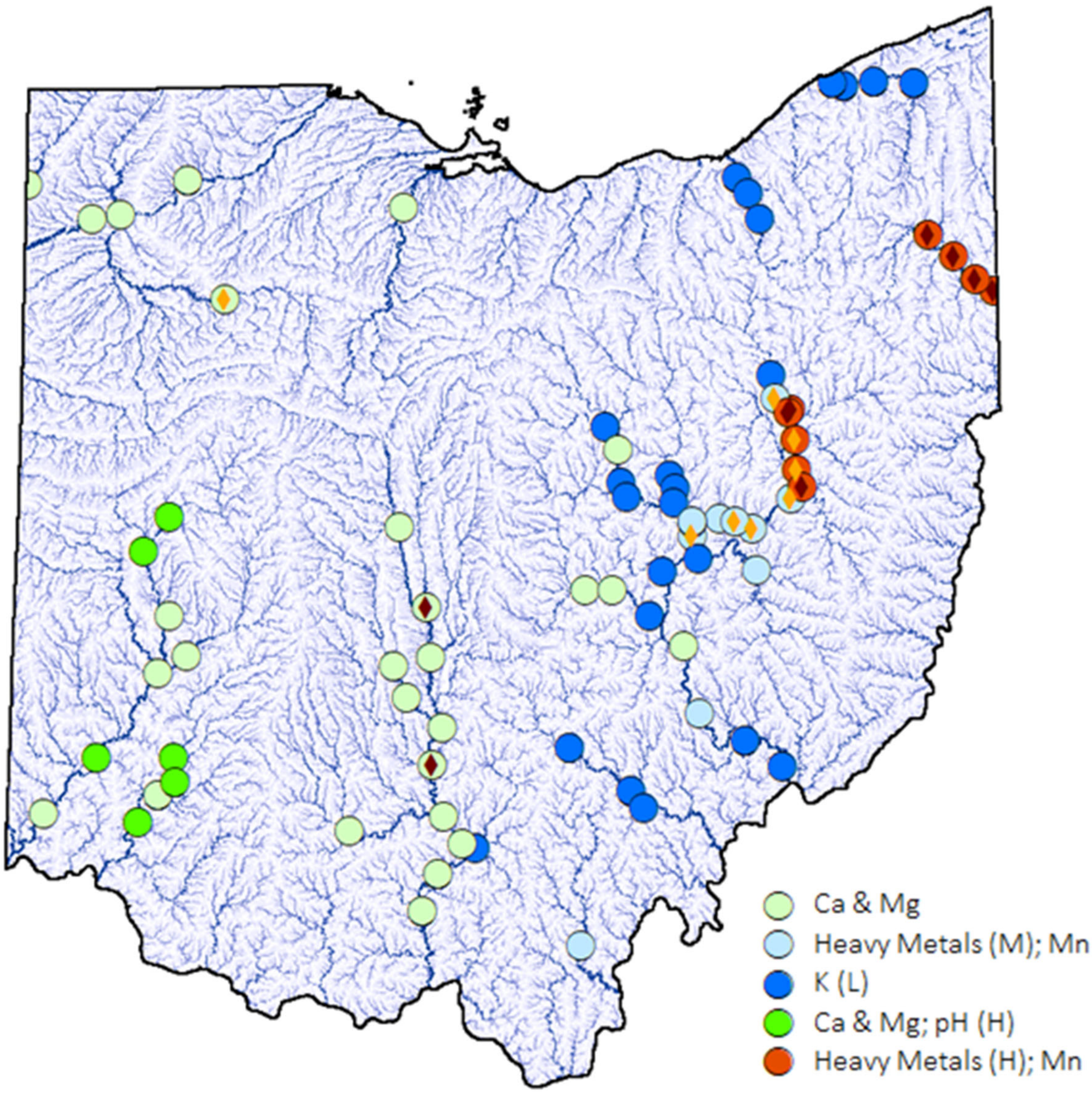


Figure 13 - Sediment sampling locations color-coded to similarities based on measured metal concentrations.

The legend narratively describes the distinguishing features. Diamonds superimposed on the location indicate that concentrations of metals have the potential to adversely affect benthic communities based on simultaneously extracted metals molar concentrations. None of the values exceeded the Tier III threshold. The maroon diamonds indicate SEM concentrations (adjusted for TOC; Ohio EPA 2010) greater than 175; the orange diamonds indicate concentrations greater than 100. These breakpoints were suggested by plotting the cumulative frequency distribution for calculated SEM values.

Table 9 - Locations where sediment metal concentrations exceeded probable effect levels given in MacDonald et al. (2000).

Metal concentrations are in units of mg/kg.

SHEET	STORET	STATION	RM	Cr	Ni	Zn
Sandy Creek						
119683	R07S71	Downstream Bolivar Dam	0.57		61	
Tuscarawas River						
120167	R06P01	SR 212	71.73		49	
120173	R10K10	CR 62	44.50		57	
Mahoning River						
120294	N03W13	Warren and Main Street	37.43	111	104	
120296	N03W21	Campbell	17.63			534
120290	602300	Lowellville, First Street	12.42	169	92	667

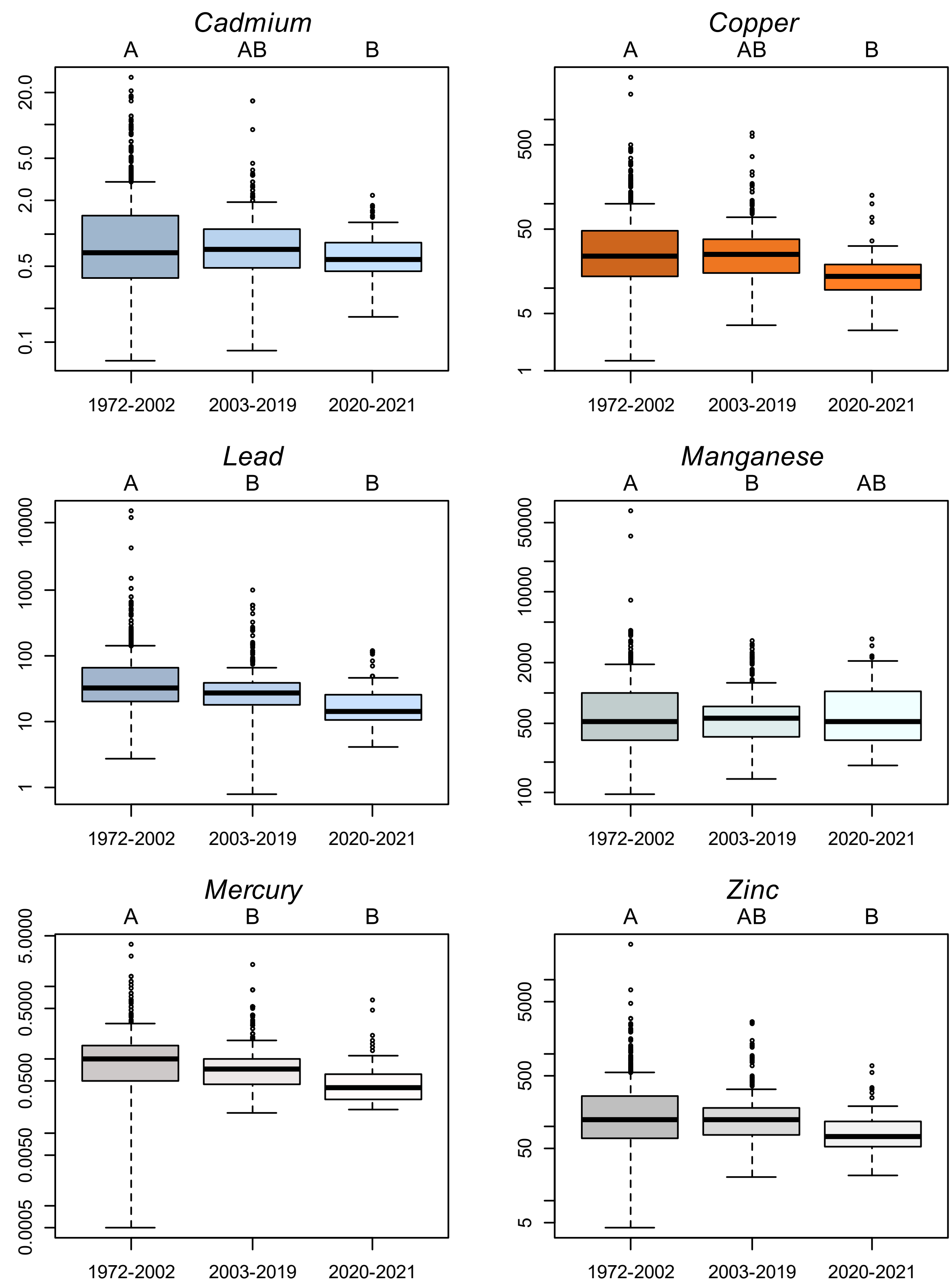


Figure 14 - Concentrations of selected metals from river sediments collected over three timeframes.

Distributions sharing a letter (arrayed along the top margins) are not significantly different.

Pollutant Loadings

Aquatic organisms are affected by the concentration of pollutants in the water. When considering pollutants discharged from permitted sources, the amount of a pollutant that can be discharged each day without causing harm to aquatic life is the basis for permit limits. This daily amount is called the pollutant load. Pollutant loads are a function of the concentration of the pollutant in the water times the volume of water discharged in a day. Permit limits are typically specified in terms of both concentrations (mg/l) and loads (kg/day) as averages over one week and one month. The averaging period is to account for expected variability in the treatment process[10]. Because loads are a product of discharge volume and concentration, loads typically mirror concentrations, as illustrated in Figure 17.

The two major pollutants discharged from publicly owned treatment works (POTWs, aka wastewater treatment plants or WWTP) are nitrogenous wastes and carbonaceous wastes. Nitrogenous wastes can be directly toxic to aquatic life when those wastes are in reduced form. Ammonia is an example of a reduced form of nitrogen. Nitrogenous wastes also result in oxygen being used up when bacteria break down those wastes. Ammonia is doubly bad because it is both toxic and oxygen consuming. Carbonaceous wastes are typically not toxic, but also cause oxygen depletion in receiving waters when being consumed by bacteria. Thus, the job of a treatment plant is to break down and oxidize waste before it is discharged. And it follows that permit limits are set for ammonia, carbonaceous biological oxygen demand (cBOD5), and total suspended solids (TSS, a measure of both nitrogenous and carbonaceous solids present). Because phosphorus is a component of domestic sewage, and because it is a plant fertilizer, phosphorus limits are also sometimes included to help prevent eutrophication of lakes and rivers. All the major (i.e., those that discharge over one million gallons of effluent per day) POTWs that discharge to the Lake Erie watershed have phosphorus limits.

Figures 18 through 24 show pollutant loadings for selected POTWs that discharge to large rivers in Ohio. These plots help illustrate how much pollution was reduced, especially from ammonia, when treatment was upgraded to advanced treatment. For the larger treatment plants serving Akron, Columbus, and Dayton, ammonia was discharged in the thousands of kilograms (1 kilogram equals 2.2 pounds) per day prior to 1988, whereas after 1988, the loadings have been in the tens of kilograms. That is a decrease of two orders of magnitude. And Akron, Columbus, and Dayton are merely examples of what took place throughout Ohio. The example shown in Figure 23 is for the Sugarcreek Water Reclamation Facility that discharges to the Little Miami River. Surveys of the Little Miami River in 1993 and 1998 documented excessive eutrophication due to phosphorus pollution. As a result, phosphorus limits were suggested for the major dischargers. Because the Sugarcreek plant uses biological nutrient removal (BNR) to achieve its phosphorus limit, it also discharges low amounts of nitrogen.

The other significant source of loadings is from combined sewer overflows. Many older cities in the Midwest and East Coast have combined stormwater and sanitary sewer systems. These combined systems are obviously vulnerable to storm events - large volumes of stormwater overwhelm the collection system and the ability of the treatment plants to handle the incoming volume. Hence, raw or minimally treated sewage is discharged as a result. Efforts have been ongoing to separate the sewers, minimize the frequency of discharge events, or otherwise capture the first flush to both prevent the treatment plant from being overwhelmed and to later treat the retained flush. One example is for the City of Columbus (Figure 25) where discharge from one of the major CSOs to the Scioto River (Whittier Street) was diverted to the Jackson Pike facility via the Olentangy-Scioto Interceptor Sewer. This diversion captures the initial flush for

[10] Treatment plants rely on bacteria to help break down wastes in a manner analogous to the human lower GI tract.

treatment, which is presumably the most polluted fraction, and bypasses the remainder. The net result appears to be a decrease in the number of discharge events and total overflow volume (Figure 26).

Similarly, in Akron, flows from a major CSO (Rack 40) that discharged to the Cuyahoga River via the Little Cuyahoga River, and several other significant CSO were diverted to storage tanks for later treatment. Again, the tanks store the initial flush up to storage capacity before bypassing the remainder. The net result is that the frequency of discharge events and total bypass volume has decreased significantly over the last decade (Figure 27).

The actions of Akron and Columbus have resulted in material improvements to the aquatic life in the Cuyahoga River and the Scioto River, as will be discussed in the ensuing sections. Many other communities in Ohio are implementing long-term control plans to either eliminate, reduce, or otherwise mitigate the impact of CSOs on receiving waters.

Agricultural Loadings

The number of agricultural conservation practices applied in Ohio increased exponentially between 1990 and 2005 (Figure 28a). The results from these practices are manifested in decreasing concentrations (see Figure 9) and detection frequencies of TSS (Figure 28b). The reduction in sediment to pollution has resulted in greatly expanded distributions and populations of sediment-sensitive fish species, as will be discussed in the ensuing chapter on aquatic life.

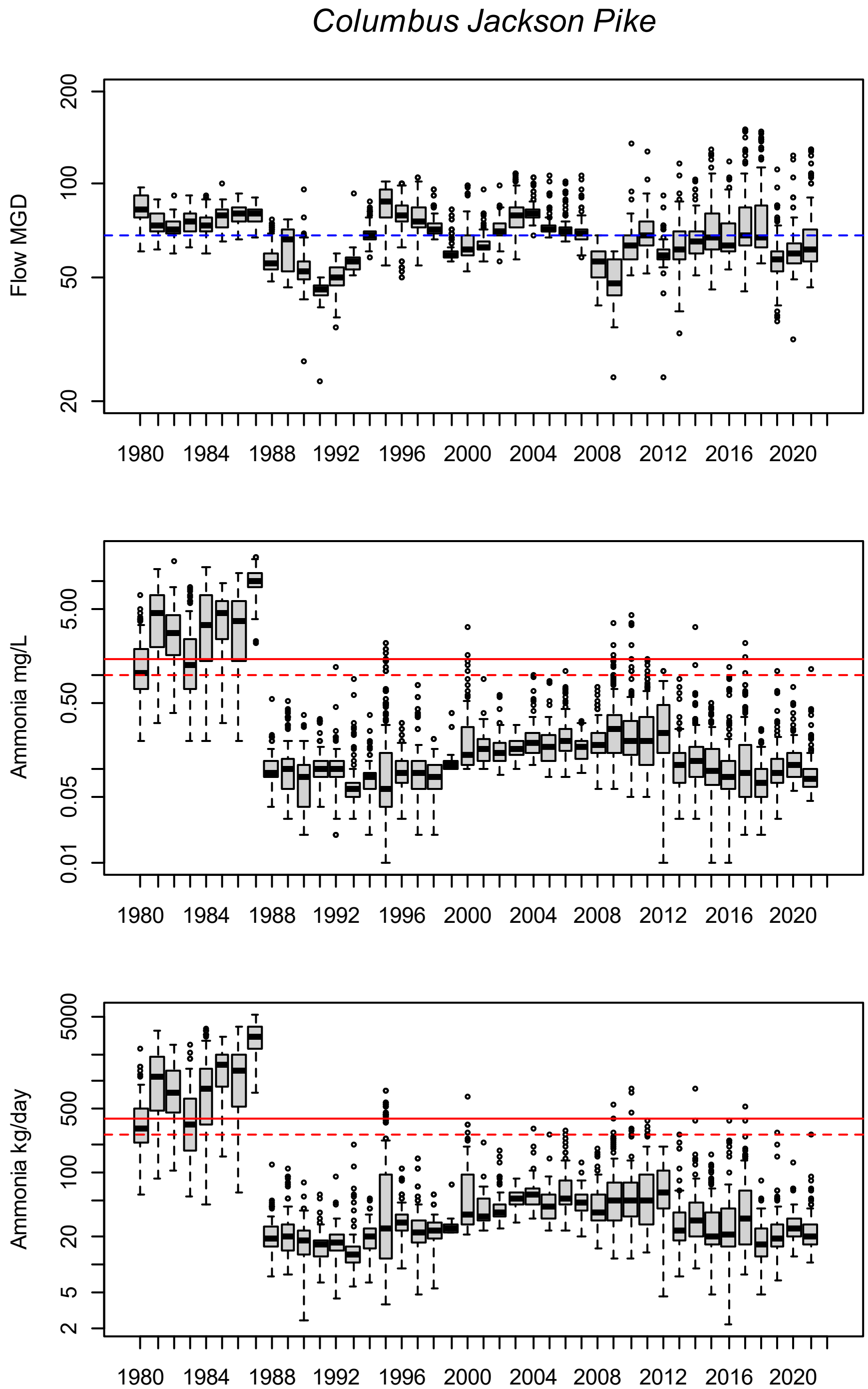


Figure 15 - An example from the Columbus Jackson Pike facility illustrating how discharge volume (Flow MGD, top panel) and concentration (middle panel) are related to loads per day (bottom panel).

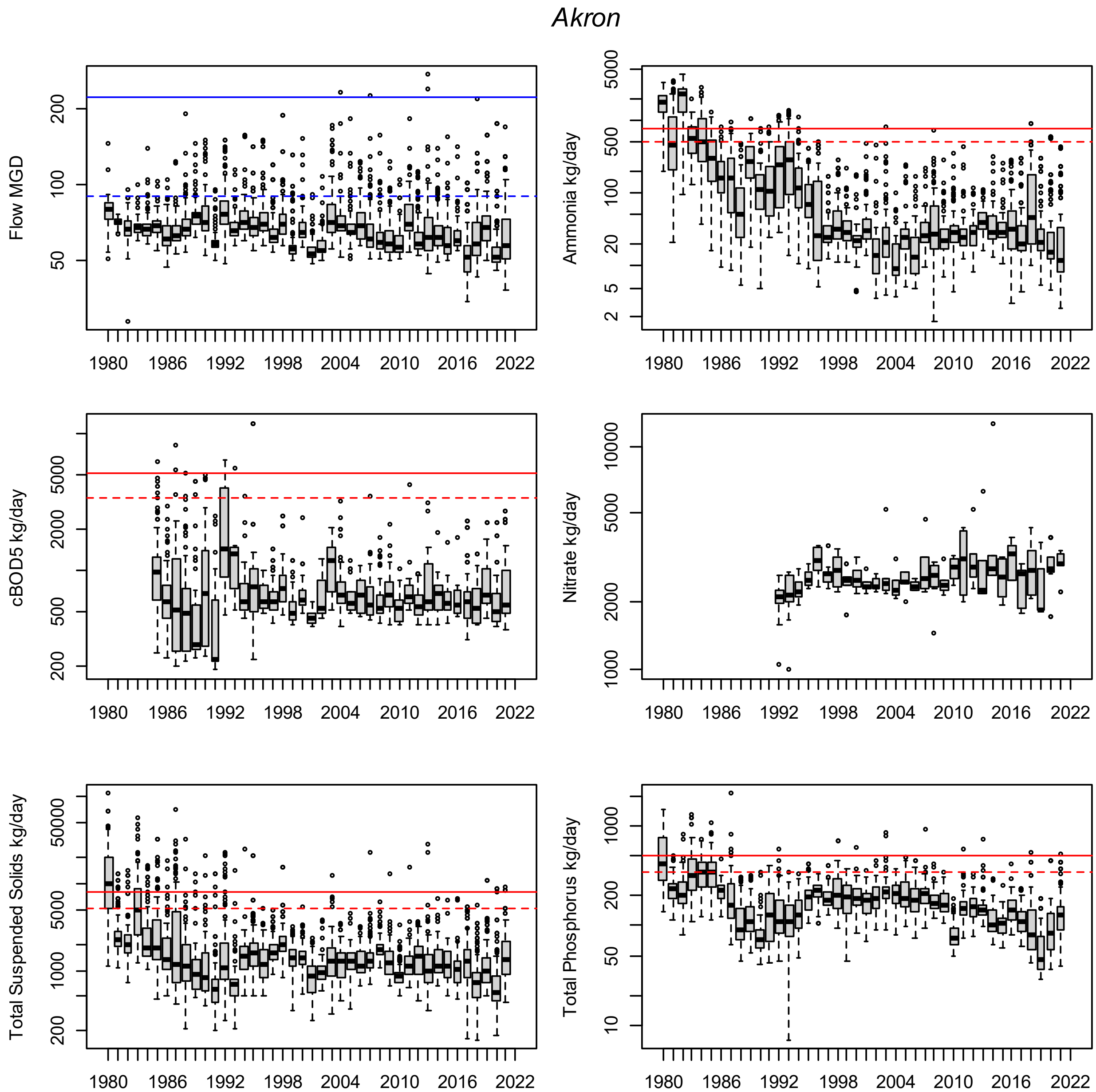


Figure 16 - Pollutant loads from the Akron facility.

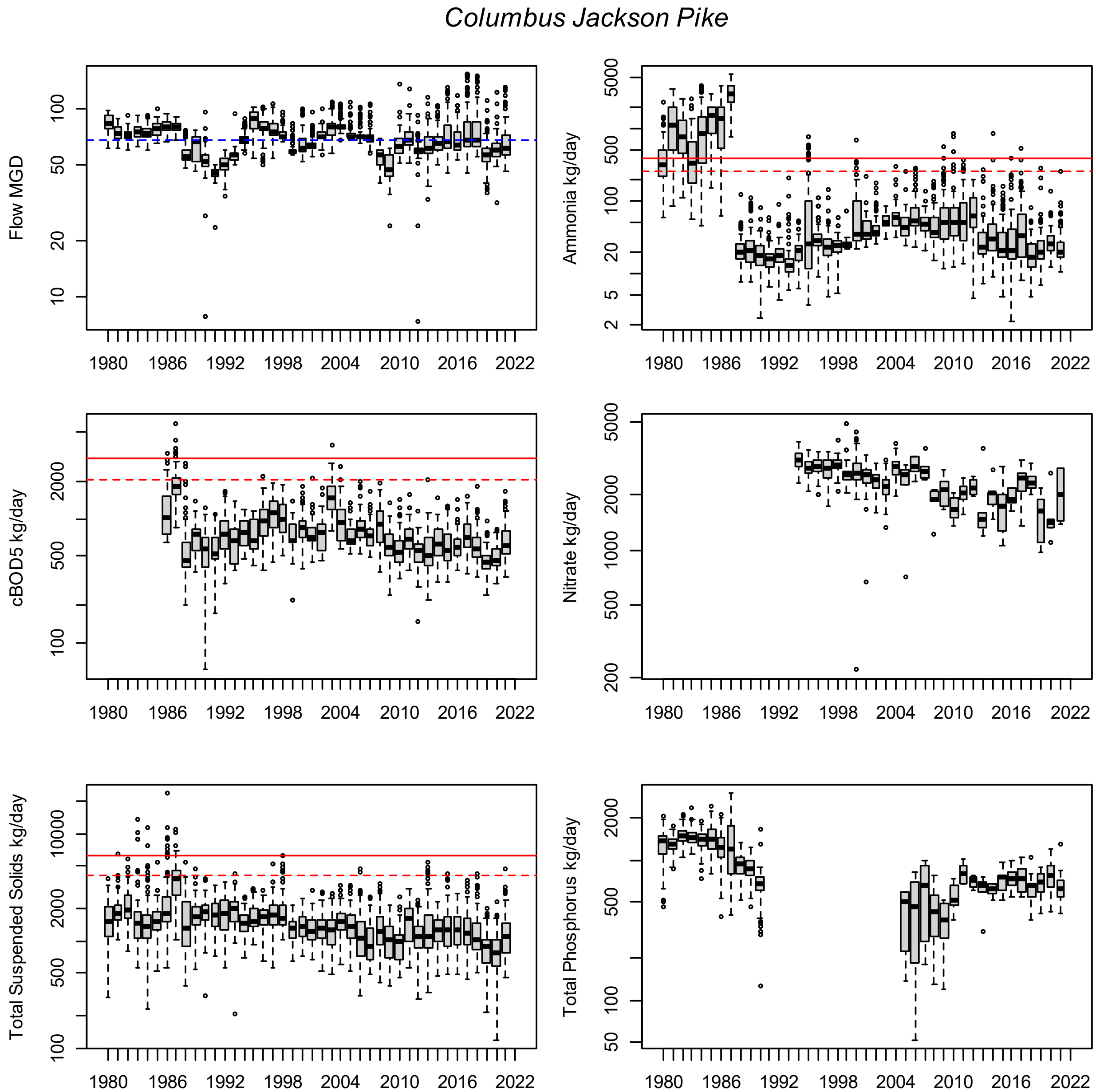


Figure 17 - Pollutant loads from the Jackson Pike facility.

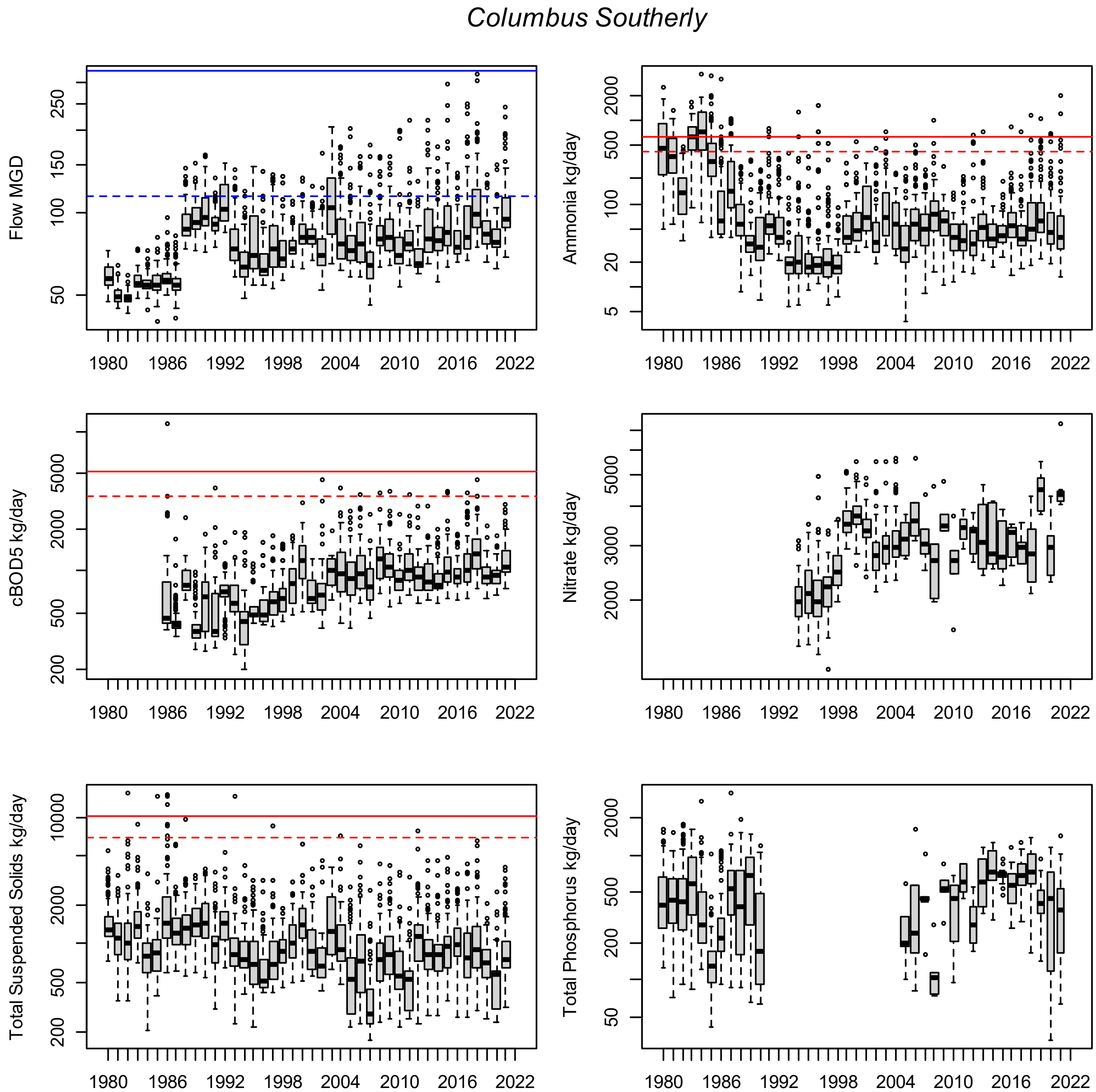


Figure 18 - Pollutant loads from the Columbus Southerly facility.

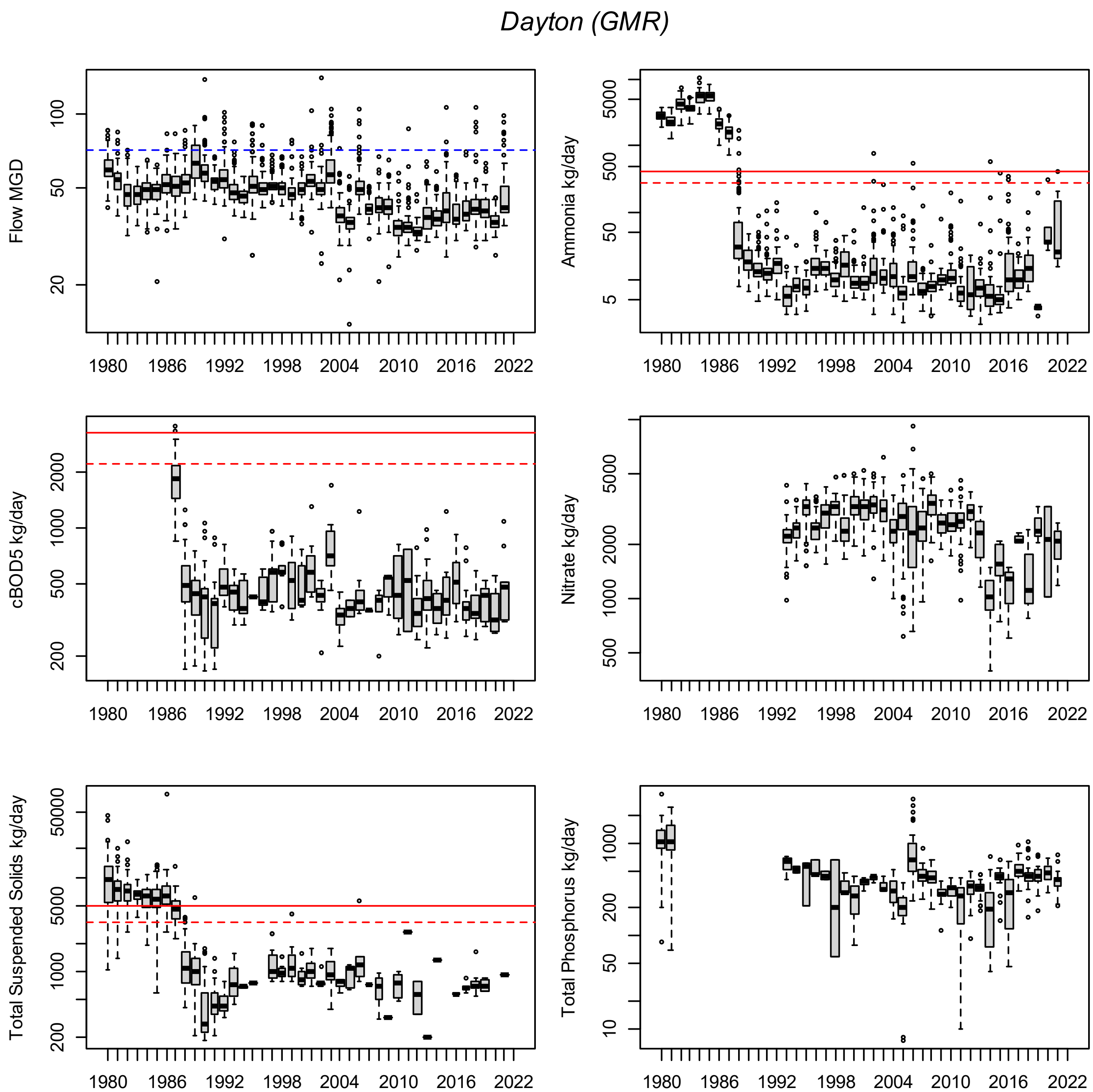


Figure 19 - Pollutant loads from the Dayton facility.

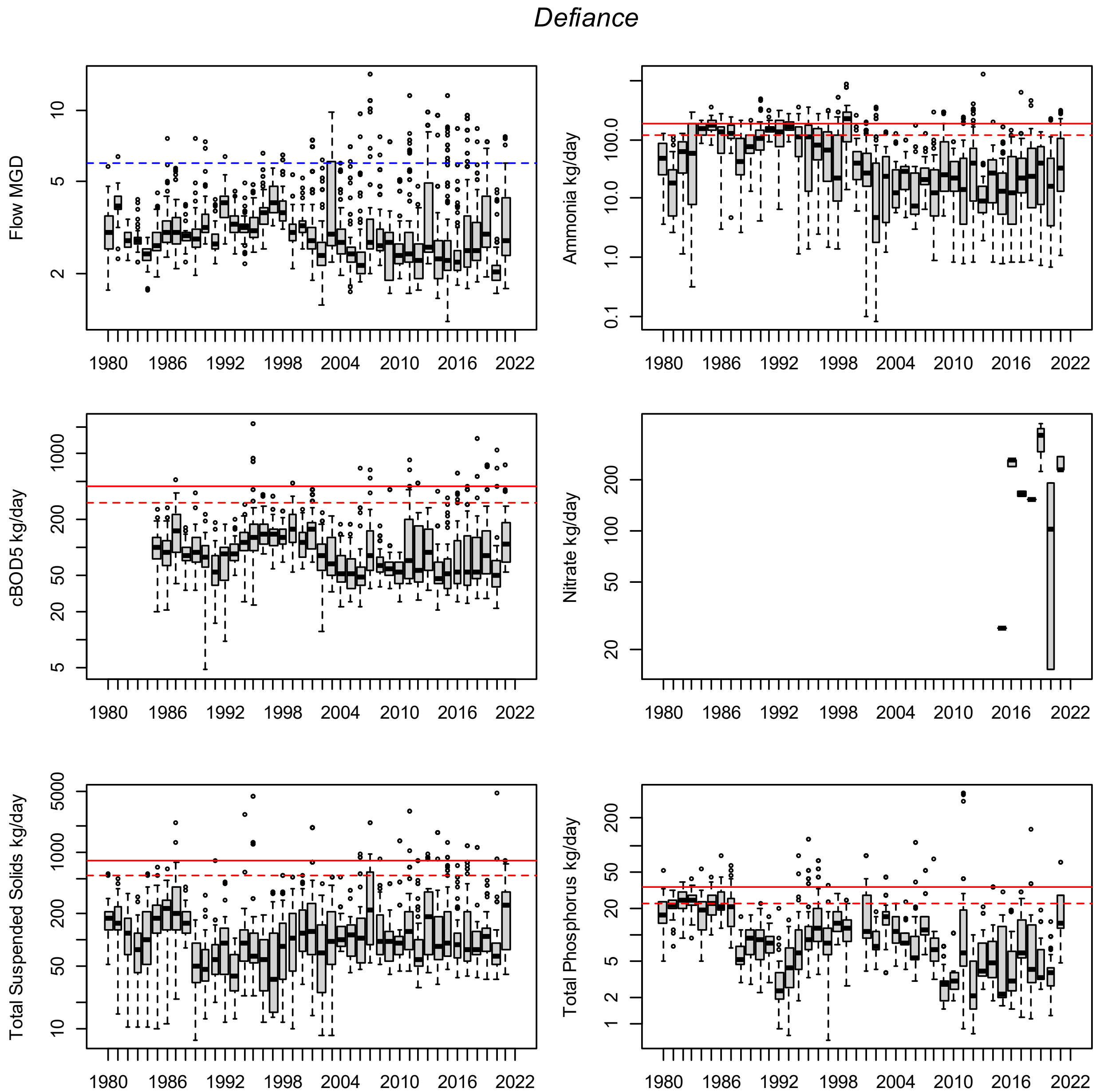


Figure 20 - Pollutant loads from the Defiance facility.

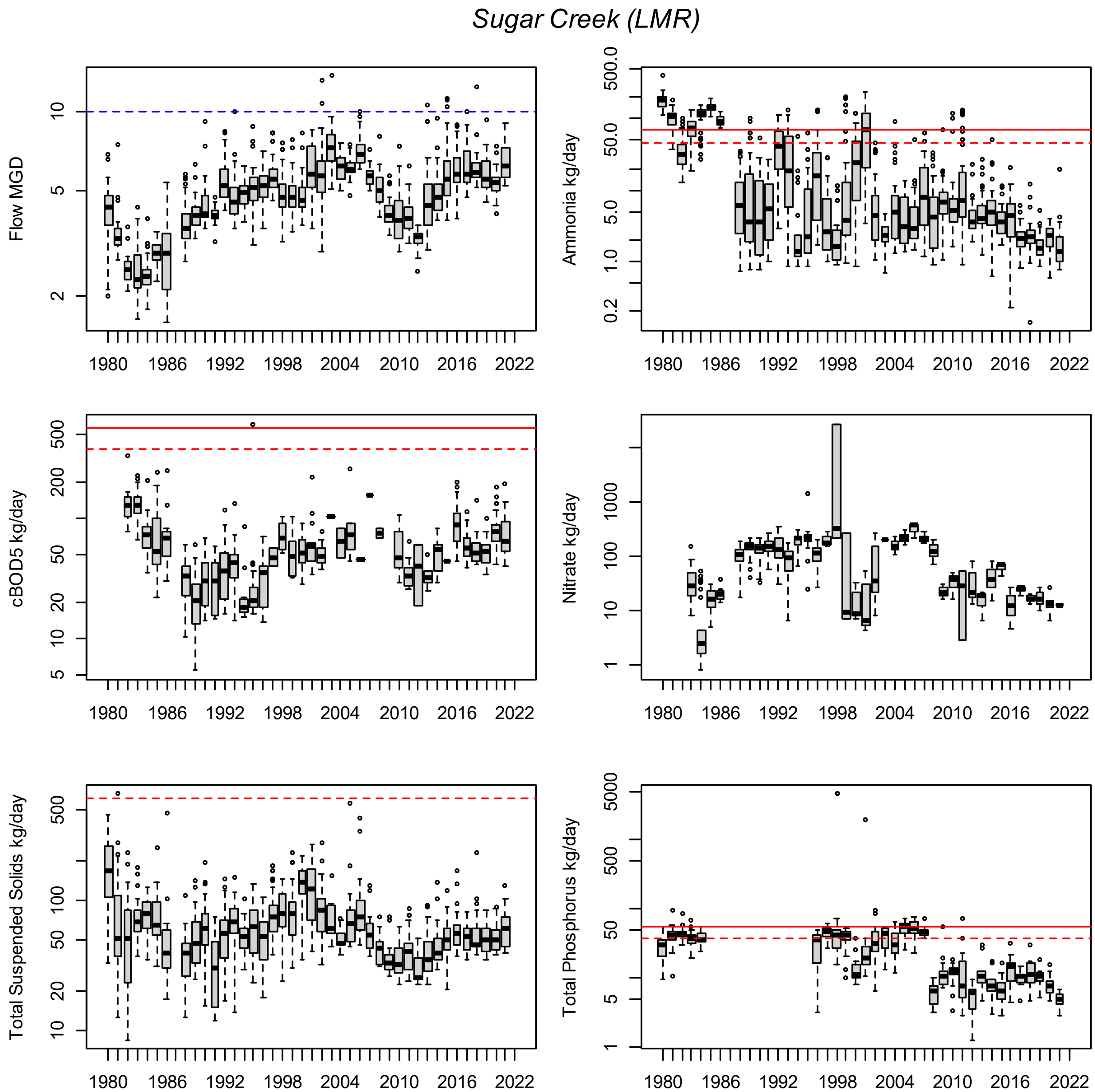


Figure 21 - Pollutant loads from the Sugar Creek (Little Miami River) facility.

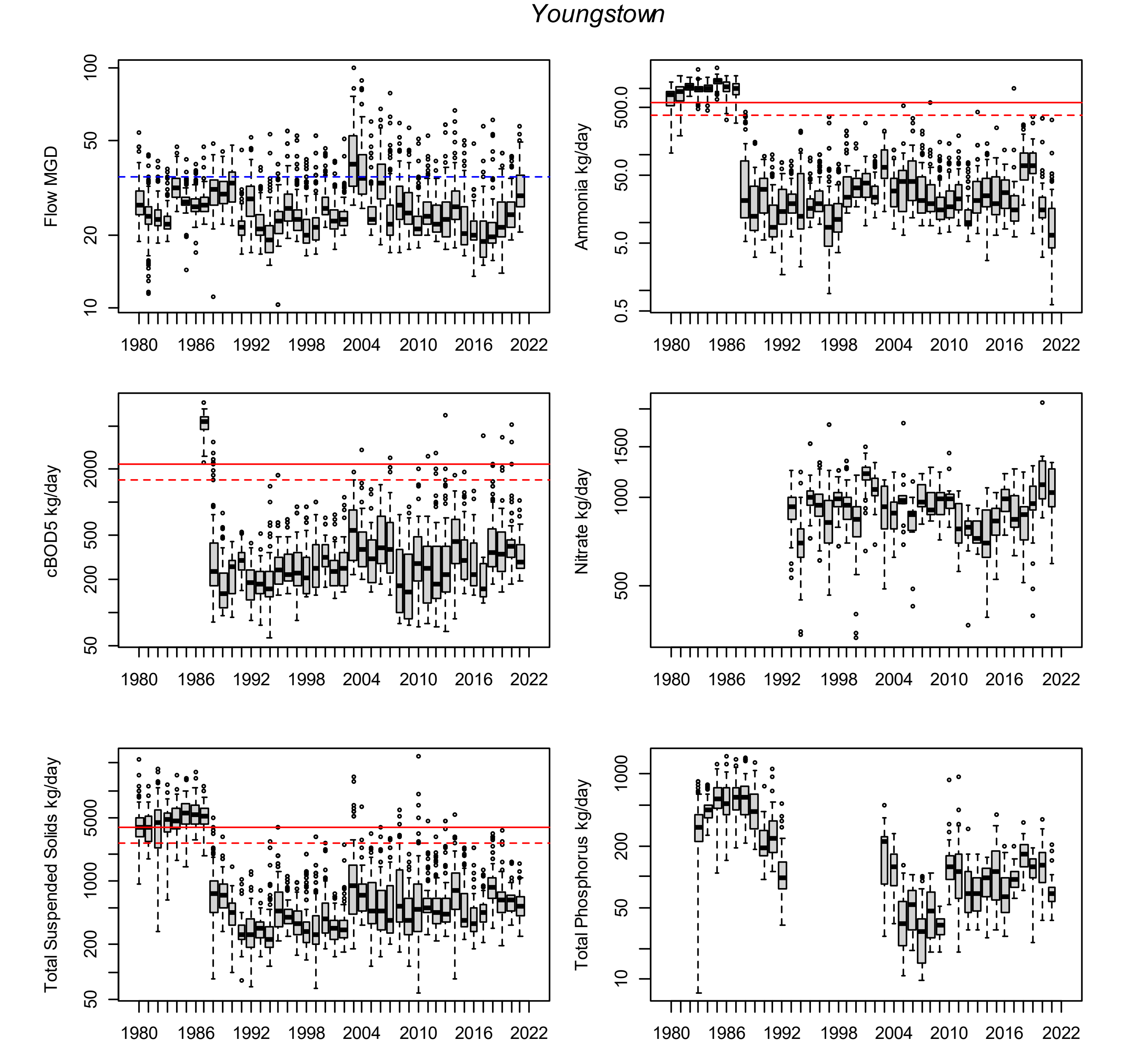


Figure 22 - Pollutant loads from the Youngstown facility.

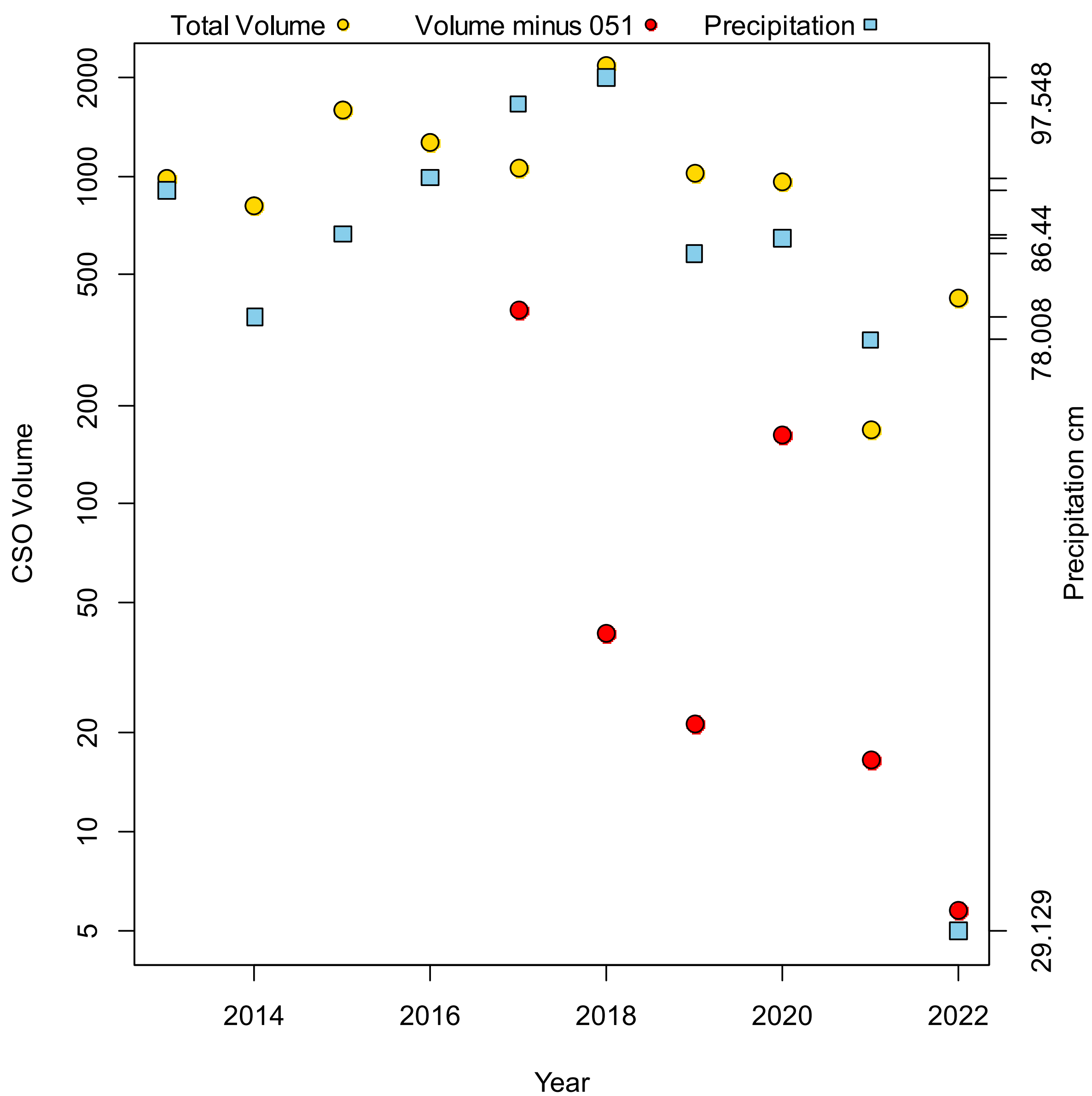


Figure 23 - Volumes of combined sewer overflows (CSO) reported by City of Columbus.

Under permit number 4PF00000 (yellow points), yearly precipitation as reported at John Glenn International Airport (blue squares), and the total CSO volume minus the volume from the 051 CSO station (red points). Discharge from 051 is diverted to holding tanks such that a fraction, presumably the worst, is retained for treatment.

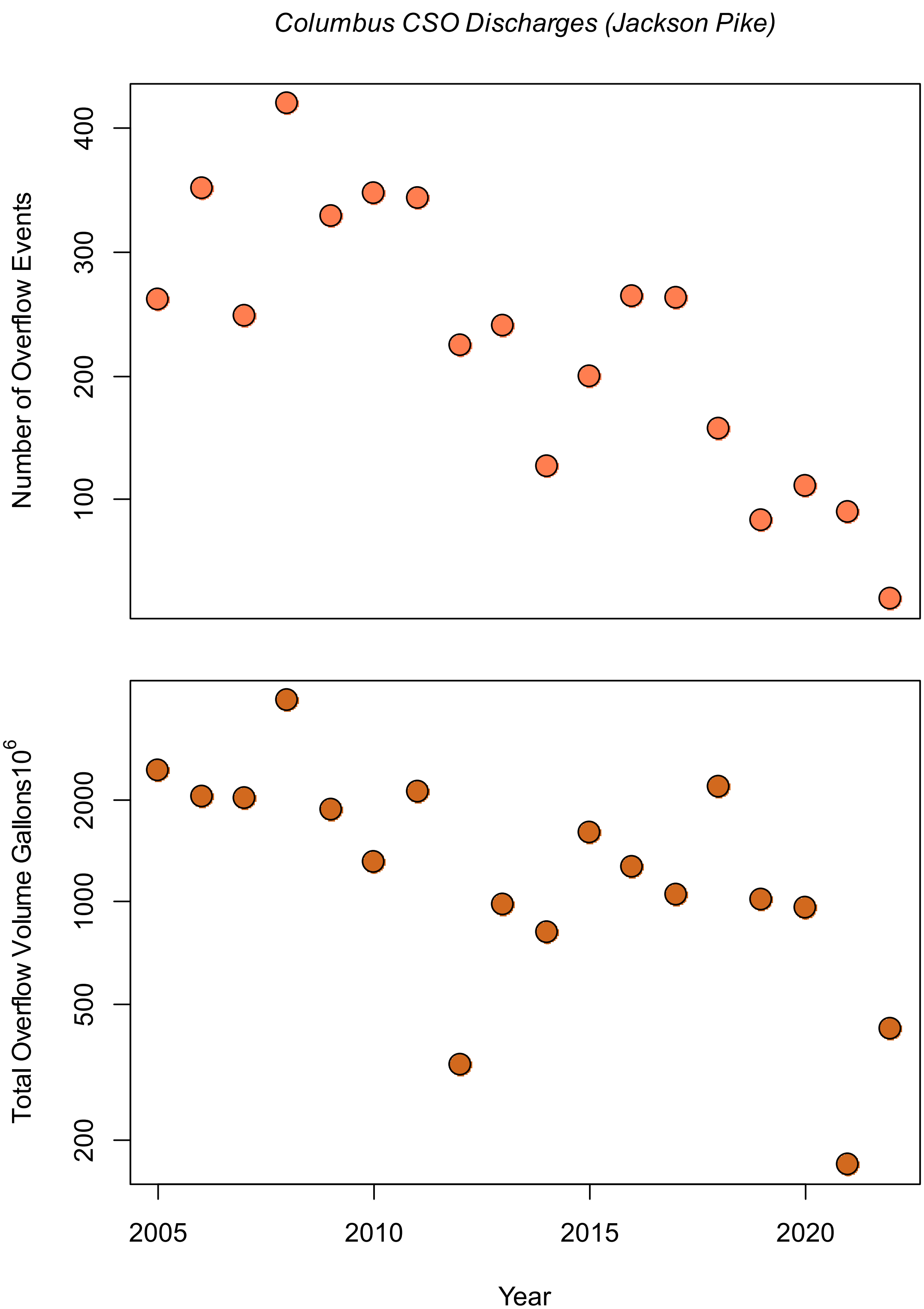


Figure 24 – Columbus combined sewer overflow discharges.

The number of overflow events (top panel) and total overflow volume for combined sewer overflows reported by the City of Columbus.

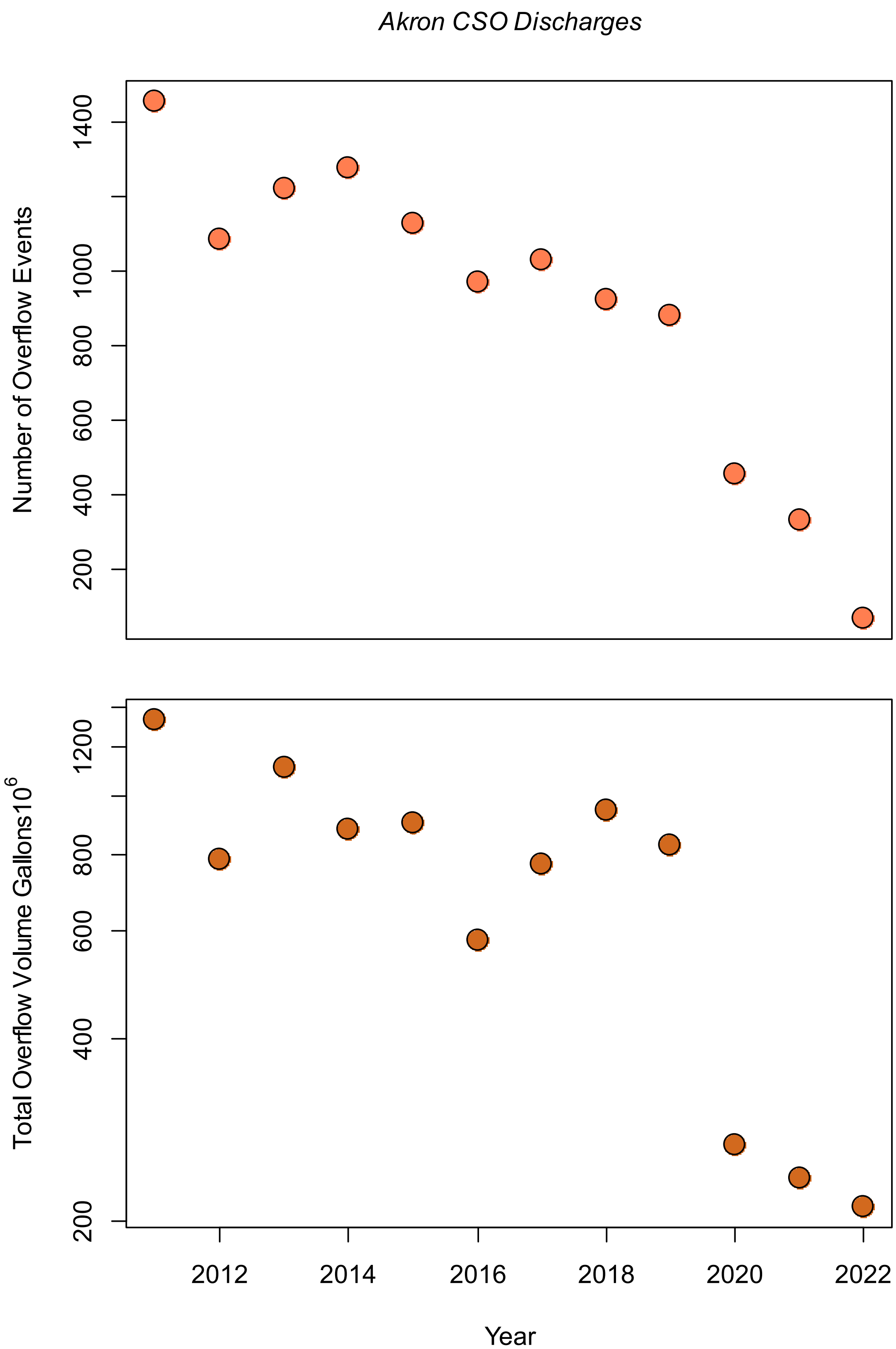


Figure 25 – Volumes of combined sewer overflows (CSO) reported by City of Akron.

The number of overflow events (top panel) and total overflow volume for combined sewer overflows reported by the City of Akron.

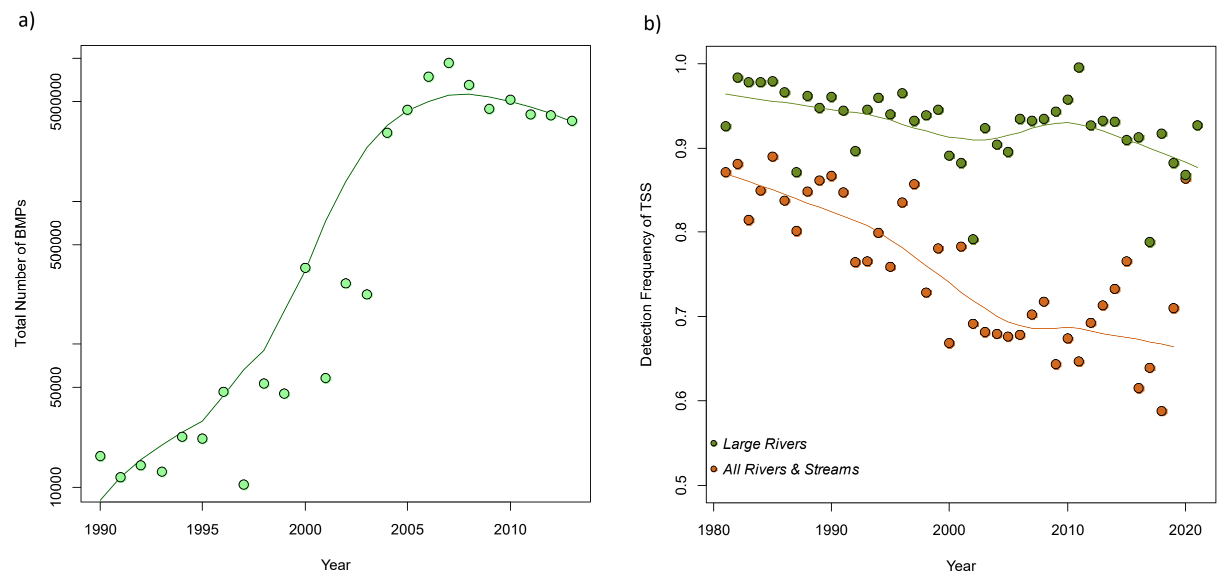


Figure 26 - Agricultural best management practices and detection frequency of total suspended solids.

a) The number of agricultural best management practices (BMPs) put in place in Ohio from 1990 through 2013; b) The detection frequency of total suspended solids (TSS) in water samples collected from Ohio rivers and streams by year for large rivers (>500 mi^2 in drainage area) and all rivers and streams. Note that a significant fraction of the TSS in large rivers is biogenic; therefore, large rivers are expected to have higher detection frequencies compared to smaller rivers.

Biological Communities - Fish: Historic Perspective and Overall Trends

The quality of fish assemblages sampled in Ohio's large rivers has improved steadily over time since standardized sampling methods were first employed by Ohio EPA in 1981. When cast over four relevant timeframes corresponding to pre-construction grants (1981-1988), post-construction grants and pre-agricultural BMP implementation (1989-2002), post-agricultural BMP implementation (2003-2019), and the most recent large river survey in 2020 and 2021, mean biological indicator scores have shown successive and statistically significant improvement at each timestep (Figure 29). The mean IBI score increased by 7.5 points from the first to second time frames, then 4.4 points and 4.3 points over the next two frames, respectively. The incidence of deformities, erosions, lesions, or tumors (DELTs) on individual fish is now at background levels established by reference sites (i.e., less than a 0.5% incidence) at most (83%) of the sites sampled (Figure 29d). This in contrast to the 1981-1987 timeframe wherein the incidence of DELTs exceeded background levels at 75% of the sites sampled, and were highly elevated (i.e., >3% incidence) at 25% of the sites sampled. This decrease directly reflects the abatement of toxins and toxic impacts to our waters.

When viewed more continuously, the effect from the implementation of the construction grants on the capture of sensitive species in large rivers shows as an inflexion point in a loess curve (Figure 30a) centered on the year 1990. Following a relatively steep increase, the curve levels off after 2005, but continues at a higher level relative to the past reflecting the added contribution of agricultural BMPs. Also note that the points for 2020 and 2021 lie above the local average, which suggests that the overall positive influence of agricultural BMPs was partially masked by targeted survey design. The trend in the relative abundance of tolerant fishes mirrors that for sensitive species (Figure 30b). The catch per effort of carp biomass was also tested, as it was supposed that the biomass appeared anecdotally to be decreasing. But the data do not apparently bear that out, at least for the large rivers. Rather, it appears improved water quality is generally beneficial (Figure 30c).

Stability of Index Measures

The precision of an analytical method is typically[11] determined by comparing the results from duplicate or split samples using the formula:

$$s = \sqrt{\frac{\sum (x_1 - x_2)^2}{2n}}$$

The level of precision in IBI and MIWB scores sampled from large rivers has narrowed over time (Figure 31). This is likely an indication of greater environmental stability, warming stream temperatures notwithstanding. At both reference sites and routine survey sites, the precision in IBI and MIWB scores improved considerably (i.e., became narrower) subsequent to implementation of the construction grants/state revolving fund program, and have remained relatively constant or trended toward less error since. Only four natural stream reference sites were resampled during the 2020-2021 large river survey, so any apparent increase or decrease in precision based on those samples in the recent frame is likely due to chance. For natural large river reference sites sampled between 2003 and 2021, the level of precision for the IBI is three points (rounded up from 2.98) and for the MIWB it is 0.48.

[11] Following the "Orange Book". Inczédy, J. and Lengyel, T., 1998. Compendium of analytical nomenclature: definitive rules 1997. Institut d'Estudis Catalans.

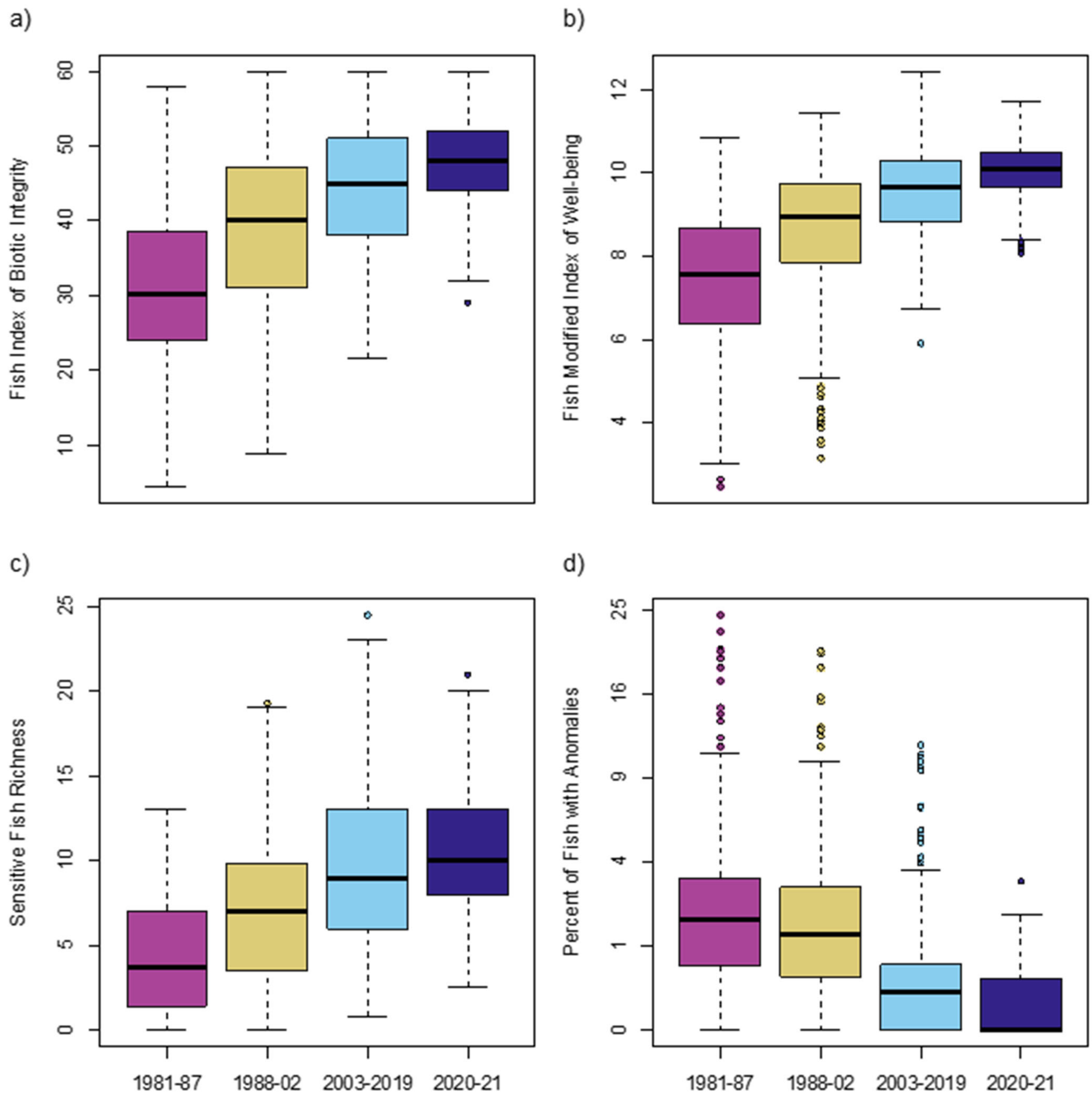


Figure 27 - Distributions of fish quality index scores, number of sensitive species, and percent of fish showing anomalous deformities, erosions, lesions, or tumors (DELTS) recorded from large rivers by time periods. a) The Index of Biotic Integrity; b) the Modified Index of Well-being; c) sensitive taxa richness; and d) the percent of fish with DELT anomalies. The means are significantly different at each time-step for all four indicators. Note that the percent of fish with DELT anomalies was modeled as a gamma distribution (using %DELT+1 to offset zeros).

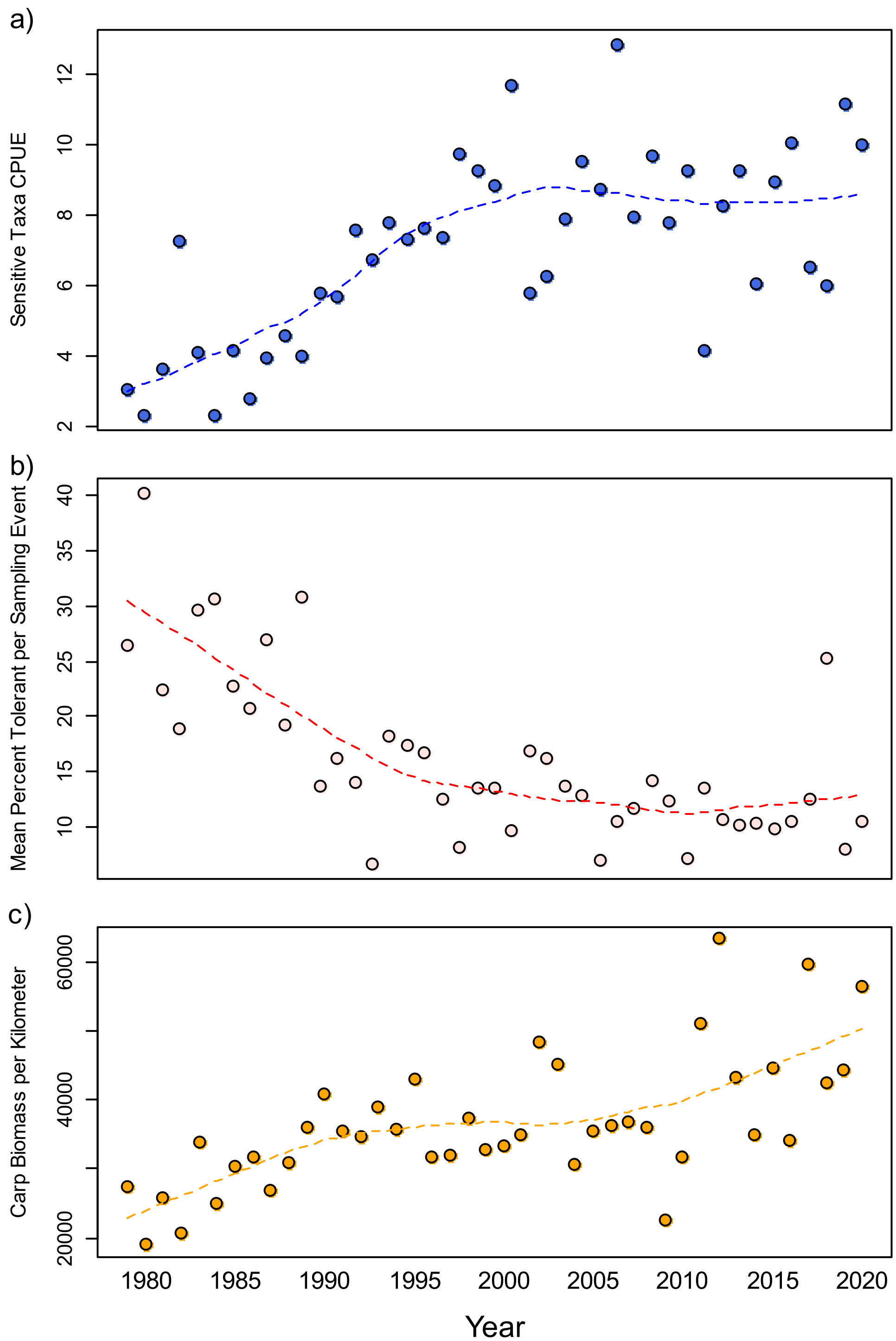


Figure 28 - Fish sampling data.

a) The number pollution sensitive fish species captured per kilometer of river sampled as a function of time; b) The average percent composition by tolerant fish per sampling event; and c) The biomass of carp per kilometer of river sampled.

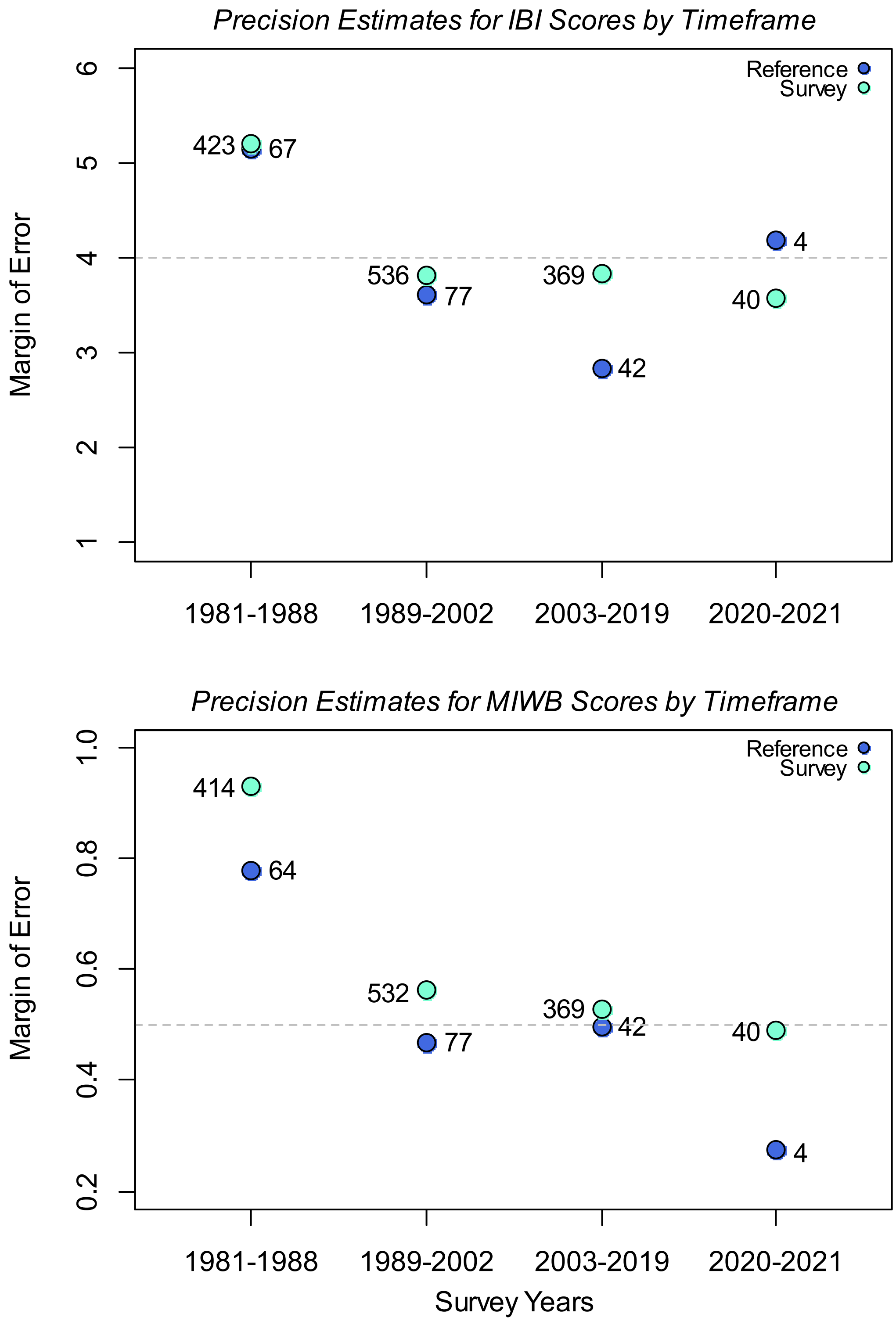


Figure 29 - Precision estimates for IBI and MIWB scores by timeframe and site type.

The gray horizontal lines in each plot represent the margin of error (i.e., the nonsignificant departure) established in Ohio EPA (1988).

Biological Communities - Macroinvertebrates: Historic Perspective and Overall Trends

Similar to what was observed with the fish community, macroinvertebrate communities in Ohio's large rivers have improved through successive time periods. With respect to the richness of pollution sensitive taxa and taxa in the orders Ephemeroptera, Plecoptera, and Trichoperta (EPT), the improvement appears distinct across time intervals (Figure 32). The ICI, on the other hand, shows an initial improvement between the early 1980s and the late 1980s-early 1990s, similar levels between the next two timesteps, followed by an increase in 2020-2021. The difference in results between the richness measures and the ICI is likely because the artificial colonizing blocks used for the ICI partially obviate habitat as a factor. Thus, the successive effect of the construction grants/revolving loan fund followed by adoption of agricultural BMPs is less apparent in the ICI scores.

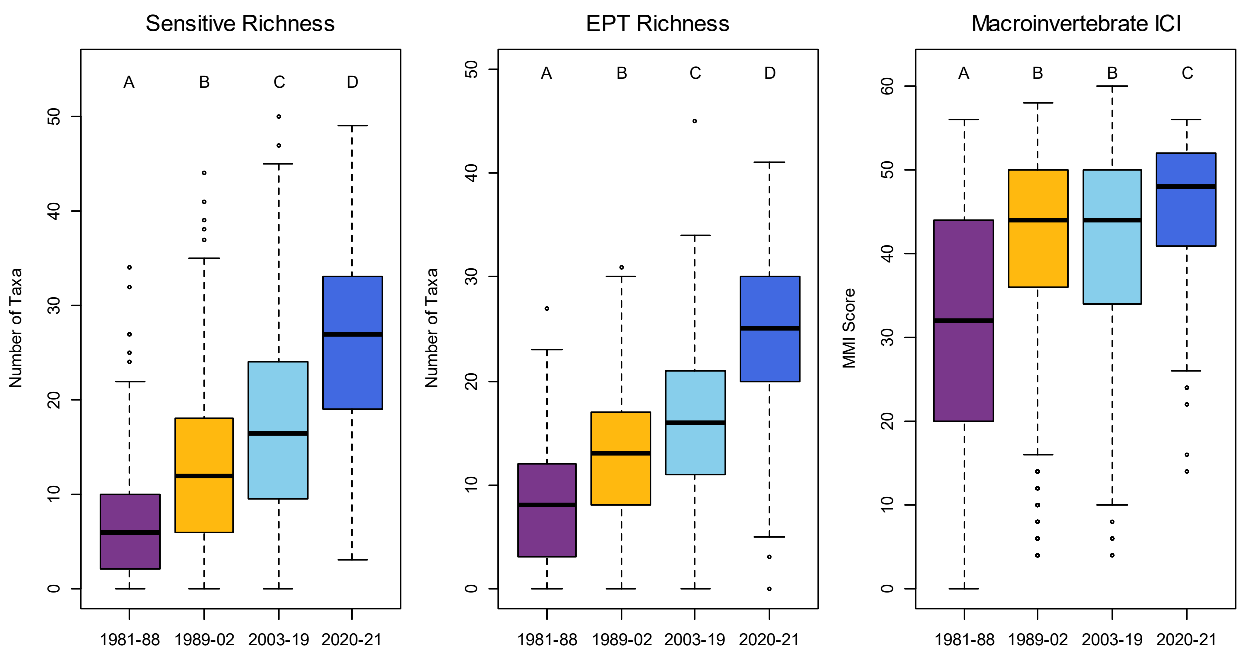


Figure 30 - Distributions of macroinvertebrate richness measures and ICI scores by four environmentally relevant timeframes.

Distributions sharing a common letter are not significantly different.

When viewed more continuously (Figure 33), both sensitive taxa richness and ICI scores show an indistinct inflexion point around 2010. This point may reflect a lag between implementation of agricultural BMPs and sediment embedding large river substrates, as channels store and remobilize sediments (Hamilton 2012). However, the trends in the plots shown in Figure 33 are essentially linear, as significant breakpoints were not detected (using the segmented package in R). Nevertheless, the trend of increasing quality is continuous over four decades and clearly driven by the combination of management efforts applied to our rivers, streams, and landscape.

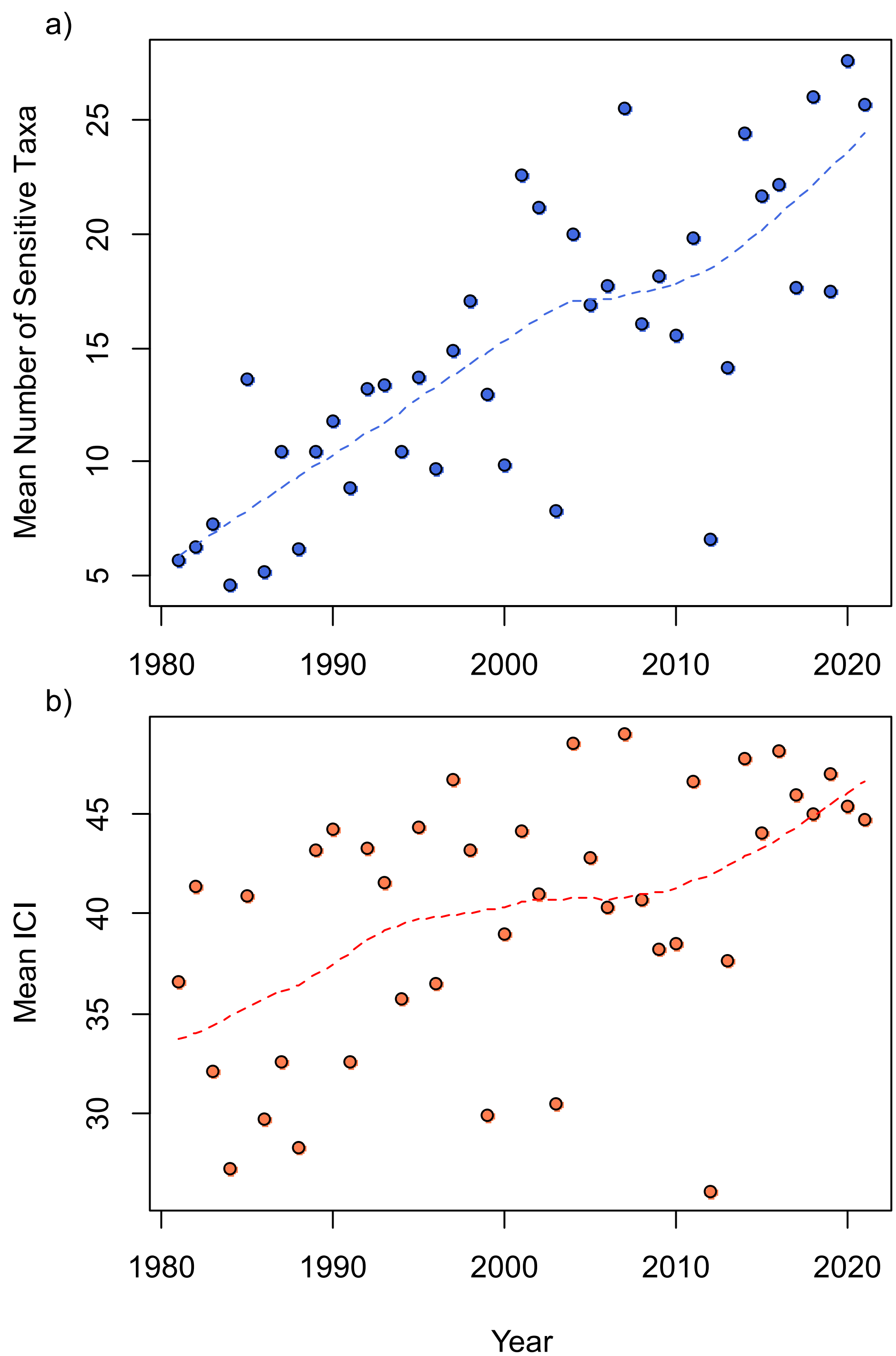


Figure 31 - Sensitive taxa richness and mean ICI score by year.

a) Mean sensitive taxa richness, and b) mean ICI score by year. Trend lines are drawn by loess (span=0.5, degree=1).

Biological Trends by River - Summary

Taken as an average across all rivers, biological index scores increased significantly between 2003-2019 and 2020-2021. IBI scores increased by 3.1 points, MIWb scores by 0.50 points, and ICI scores by 5.2 points. Also, the number of sensitive macroinvertebrates collected averaged 26 taxa in 2020-2021 compared to 17 taxa in 2003-2019. The overall direction of IBI scores for individual rivers across all time periods is significantly positive in 24 rivers, neutral in four, and negative in one (the Mohican). For the MIWb, the trend is significantly positive in 26 rivers, and neutral in three. For the ICI, the trend is significantly positive in 16 rivers, neutral in 13. Sensitive macroinvertebrate taxa richness shows a positive trend in 24 rivers, and neutral in five. Neutral trends for the IBI, MIWb and sensitive taxa were observed in relatively unperturbed rivers (e.g., the Grand River).

Relative to the 2003-2019 timeframe, if mean biological index scores from 2020-2021 differed from 2003-2019, the difference was typically not significant. In making 29 comparisons of means for the individual rivers, especially assuming all things being equal (i.e., in terms of water quality and habitat), chance would dictate that some means will be higher and some lower. That said, where significant differences were detected, the direction was positive, especially for sensitive macroinvertebrate taxa, and positive in all cases but one. The Mohican River experienced a significant decrease in fish index scores coincidental with increases in suspended sediment and TKN (this pattern was observed more generally in the upper Muskingum watershed). And as previously stated, the significant increases in sensitive taxa richness in the recent timeframe suggests that our large rivers continue to purge sediment accumulated from past abuse. Figures 34, 35, 36, and 37 visually chart the change in mean biological index scores for each river over environmentally relevant time periods. Table 10 lists linear rates of change in biological indicators since 1981, and differences observed between the 2003-2019 and 2020-2021 timeframes.

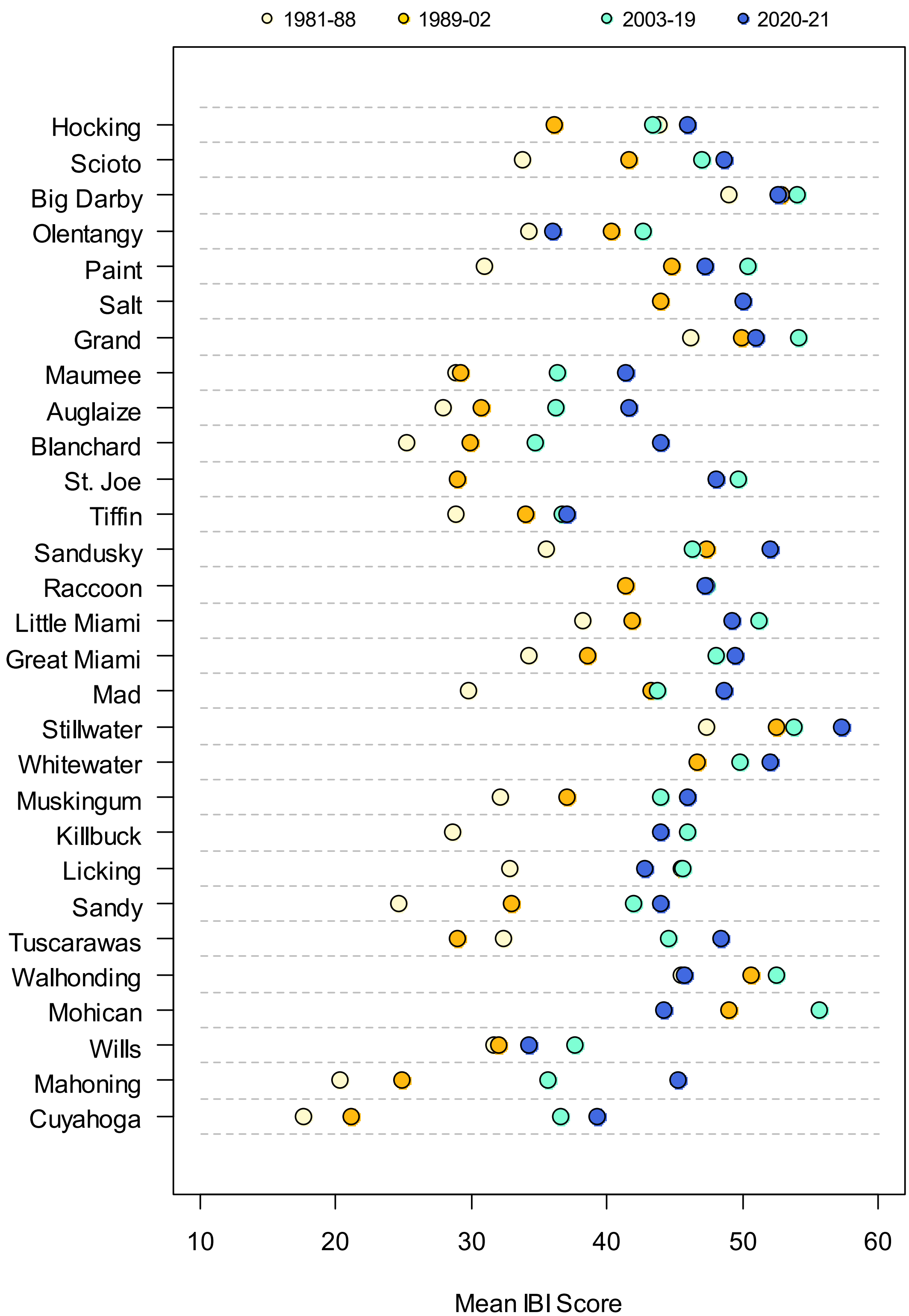


Figure 32 - Mean Index of Biotic Integrity (IBI) scores for four relevant time periods for each of Ohio's large rivers.

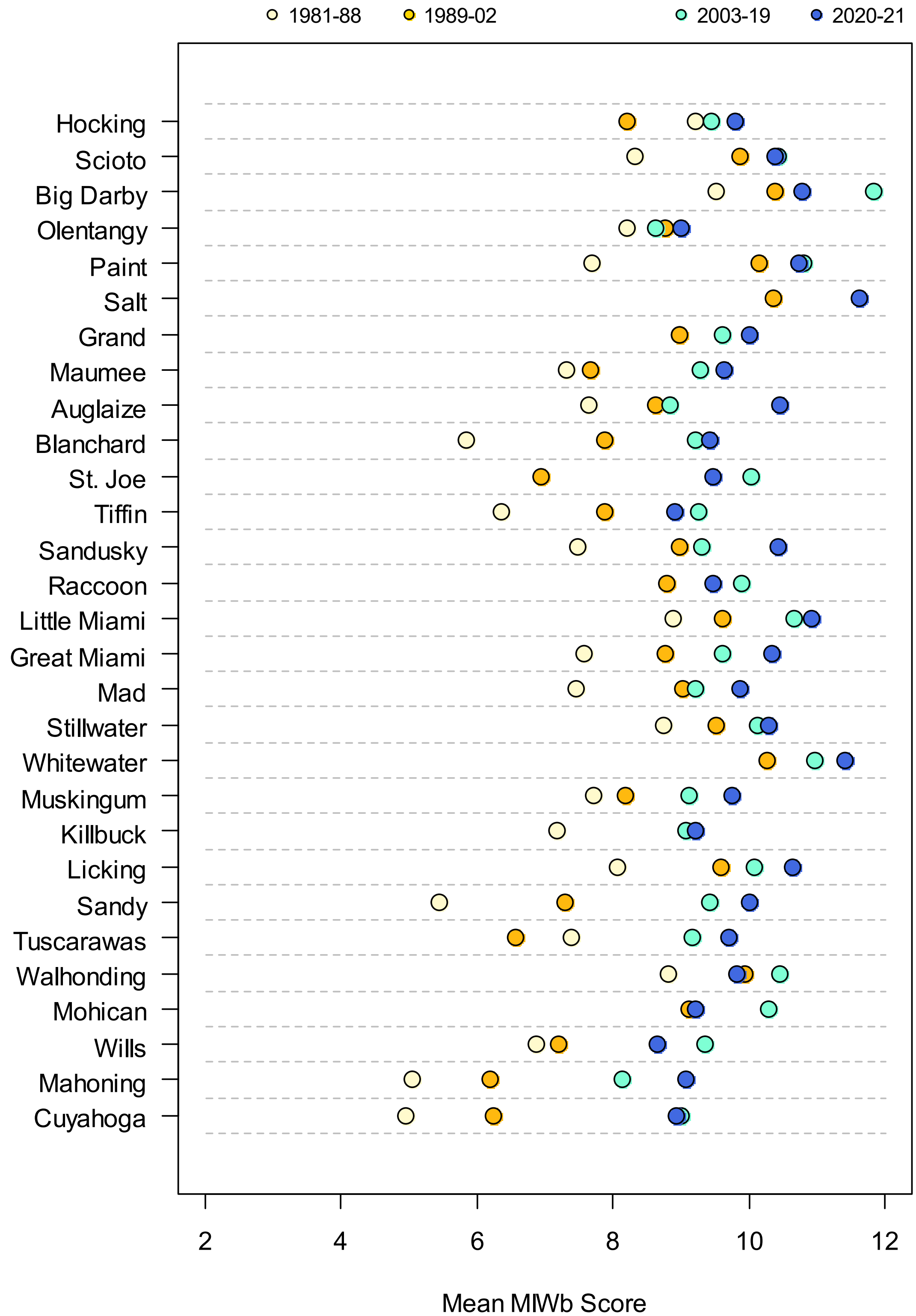


Figure 33 - Mean Modified Index of Well-being (MIWb) scores for four relevant time periods for each of Ohio's large rivers.

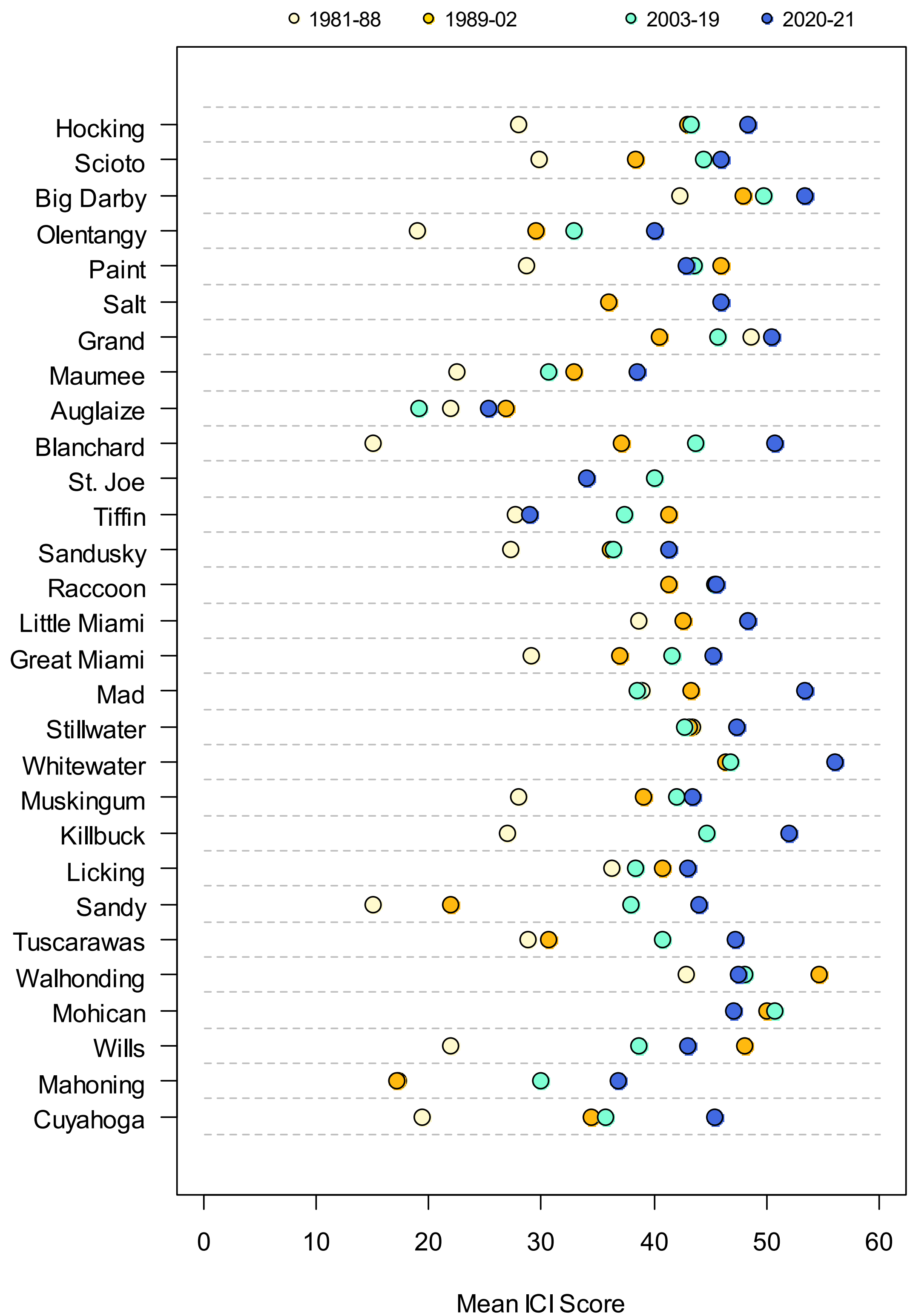


Figure 34 - Mean Invertebrate Community Index (ICI) scores for four relevant time periods for each of Ohio's large rivers.

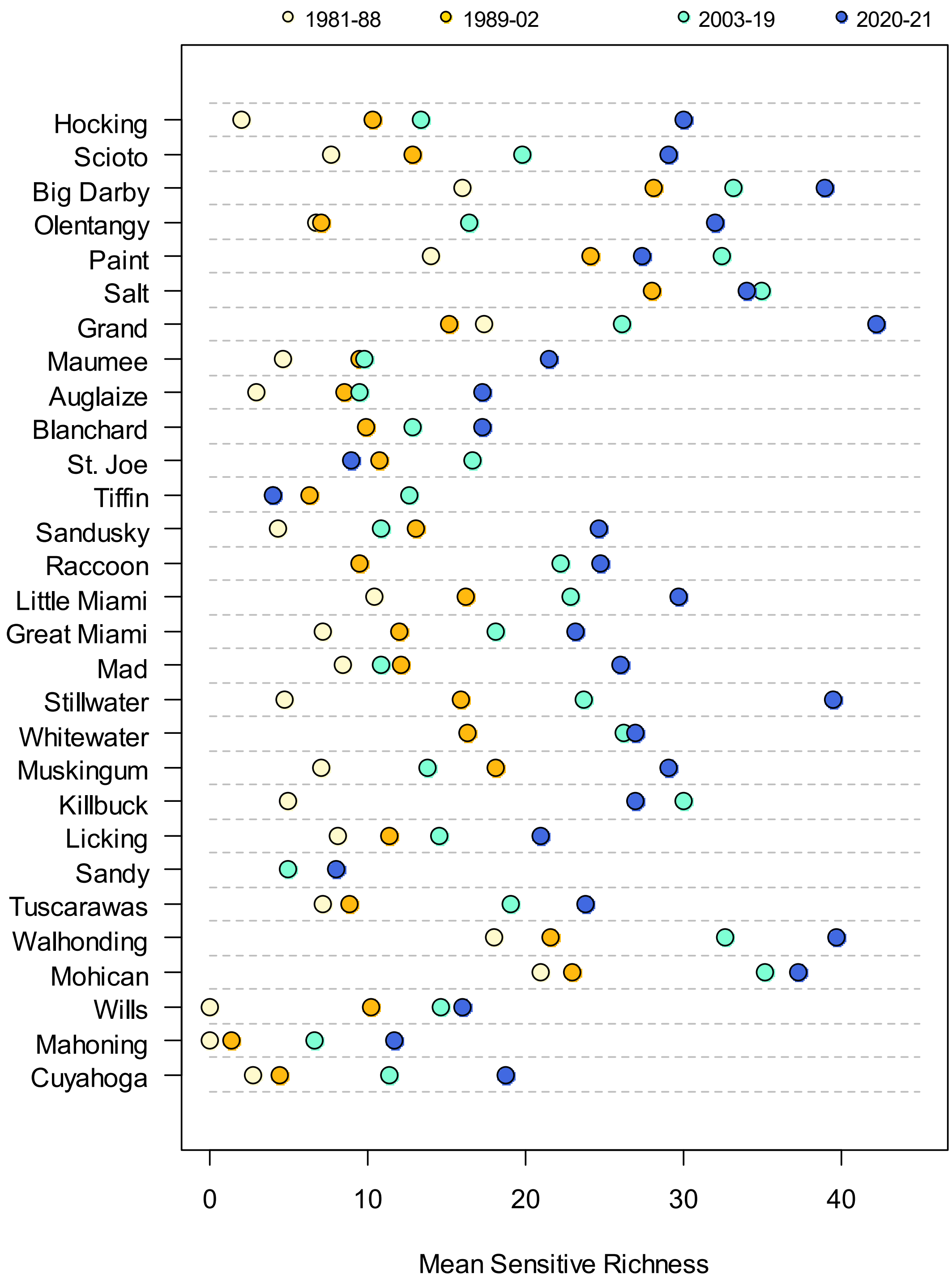


Figure 35 - Mean number of sensitive taxa sampled from each of Ohio's large rivers for four relevant timeframes.

Table 10 - Linear rates of change in biological index scores and sensitive taxa richness, and differences in scores (or richness) observed between the 2003-2019 and 2020-2021 timeframes.

Cells shaded blue denote significantly positive increases. Cells shaded green denote positive trends (at the p 0.05 to 0.10 level), and unshaded cells are not significant. Statistics for the IBI, MIWB and ICI from Salt Creek (02-600-000; Scioto basin) were not calculated. Red-shaded cells show a significant negative direction.

	IBI		MIWB		ICI		Sensitive Taxa	
River	Average Increase Since 1981	Difference 2003-19 to 2020-2021	Average Increase Since 1981	Difference 2003-19 to 2020-2021	Average Increase Since 1981	Difference 2003-19 to 2020-2021	Average Increase Since 1981	Difference 2003-19 to 2020-2021
Hocking	3.3	2.7	0.59	0.35	4.2	5	8.5	16.6
Scioto	5.9	1.6	0.91	-0.03	6.5	1.6	6.7	9.3
Big Darby	1.6	-1.3	0.73	-1.04	3.6	3.6	5.9	5.8
Olentangy	3.4	-6.7	0.2	0.38	6.8	7.1	5.8	15.6
Paint	4.7	-3.2	0.81	-0.05	2.2	-0.7	4.4	-5.1
Salt	3		0.63		5		3	-1
Grand	2.4	-3.2	0.39	0.39	1	4.9	7.2	16.1
Maumee	4.3	5	0.9	0.36	4.3	7.9	4.2	11.7
Auglaize	4.5	5.5	0.81	1.6	0	6.1	4.1	7.8
Blanchard	5.8	9.3	1.29	0.22	1.1	6.9	3.5	4.5
St. Joe	13	-1.7	1.84	-0.55	-2.1	-6	1.2	-7.7
Tiffin	2.9	0.3	0.98	-0.34	0.6	-8.3	2.6	-8.7
Sandusky	4.6	5.7	0.87	1.13	4	4.9	5	13.8
Raccoon	3.2	-0.1	0.4	-0.41	2.2	0.2	8.2	2.5
Little Miami	5.3	-2	0.79	0.25	4.1	0	6.4	6.9
Great Miami	6.2	1.4	0.91	0.71	5.2	3.7	5.6	5.1
Mad	6	4.9	0.77	0.64	2.4	14.8	3.8	15.1
Stillwater	3	3.6	0.58	0.18	0.6	4.6	1	15.7
Whitewater	3	2.2	0.65	0.44	2.1	9.2	7.9	0.7
Muskingum	5.1	2	0.68	0.63	5.9	1.4	5.4	15.3
Killbuck	5.6	-2	0.72	0.14	8.4	7.3	7.7	-3
Licking	4.1	-2.9	0.87	0.56	1.5	4.6	3.8	6.4
Sandy	6.7	2	1.58	0.59	10.3	6	3	3
Tuscarawas	6.3	3.8	0.93	0.53	6.3	6.5	5.9	4.7
Walhonding	0.7	-6.7	0.41	-0.63	1.2	-0.5	7.7	7.1
Mohican	**-6.5**	**-11.5**	-0.46	**-1.07**	-2.5	-3.7	6.4	2.1
Wills	1.6	-3.4	0.84	-0.71	5.2	4.3	4.2	1.3
Mahoning	9	9.6	1.6	0.92	8.6	6.9	5	5.1
Cuyahoga	9.5	2.7	2	-0.06	7.8	9.6	4.5	7.4

Recent Biological Condition - Fish Communities

The biological condition of fish communities sampled during the 2020-2021 Large River survey rate good or better for 89 percent of the IBI scores and 95 percent of the MIWb scores reported. Scores rated as fair for the IBI and MIWb accounted for 3 percent and less than 1 percent, respectively. When applied to stream miles, over half of the large river miles are in excellent condition, roughly 40 percent are in good condition and 10 percent are in marginal or fair condition (Figure 38).

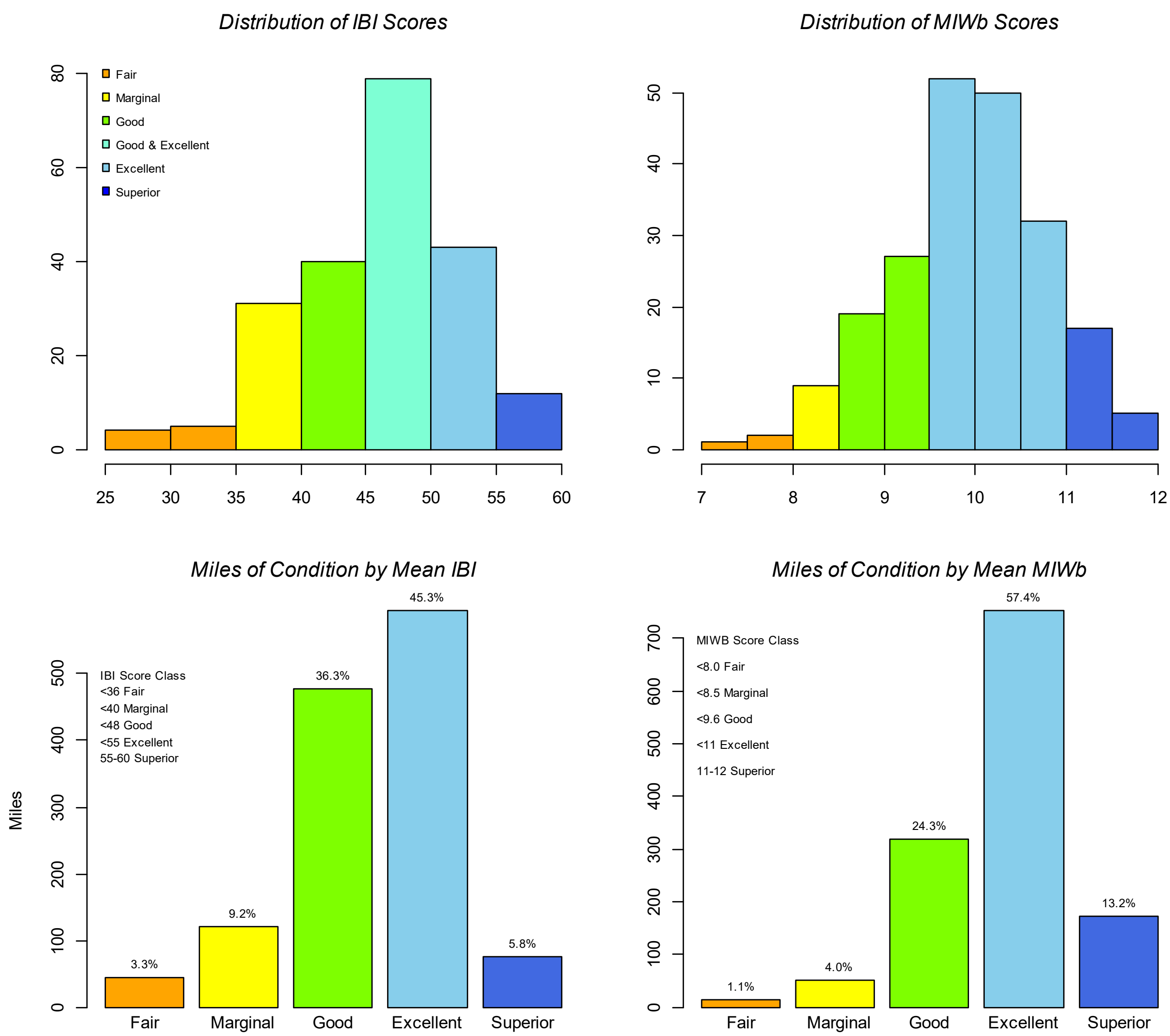


Figure 36 – Recent Biological Condition – Fish Communities

Distributions of individual fish index scores (top row) and miles of condition classified based on mean index scores (bottom row). Note that good and excellent IBI scores fall within the 45-50 IBI interval in the upper left-hand histogram.

Fish community condition is related to three major environmental gradients. The first is a gradient of habitat quality plus organic and nutrient enrichment[12]. The second is a eutrophication gradient, and the third is a gradient that reflects legacy contamination from mining and industry (Figure 39). The rivers with fish communities negatively influenced by organic enrichment and marginal habitat (the blue-colored sites in Figure 39) are primarily the Maumee and Auglaize rivers. Note that these sites are also eutrophic, as evidenced by their position on the x-axis. Excessive eutrophication affected sites in the lower Scioto River, the Muskingum River, and the Great Miami River. Rivers where legacy impacts from mining, as inferred by relatively high levels of TSS, manganese, sulfate, and aluminum, include Wills Creek, and the upper Muskingum River watershed (Killbuck Creek, Mohican, Walhonding, and Tuscarawas Rivers) and Raccoon Creek. Rivers impacted by industrial legacy include the Tuscarawas, Mahoning, and Cuyahoga Rivers. These rivers also tended to have the highest levels of sediment contaminants.

In many instances the fish community met the applicable biological criteria despite the presences of stressors. This is especially true where hypertrophic conditions were documented for the Scioto River (downstream from RM 130) and the Great Miami River (downstream from RM 60). The fish communities in both rivers performed at or near levels consistent with an exceptional warmwater habitat (EWH) designation and would likely fully do so if the stress from eutrophication was reduced. Water quality and fish assemblages in the Muskingum River would also likely benefit from reduced levels of eutrophication. The juxtaposition of sites in Figure 39 demonstrates that the fish indices for large rivers are not particularly sensitive to a eutrophication gradient. IBI scores do tend to decrease over the gradient, but MIWb scores tend to increase. This can be inferred by the position of the green and yellow-colored sites in relation to the IBI and MIWb vectors (see also the distribution of MIWb scores in Figure 40).

One curious pattern was evident in the data that suggests rivers may have differential sensitivity to the effects of eutrophication based on parent geology. It appears that rivers relatively rich in strontium are comparatively less effected (in terms of IBI scores) by eutrophication. Figure 41-b shows IBI scores modeled against pheophytin and strontium[13]. IBI scores decrease across the range of pheophytin[14] concentrations, but the decrease is less pronounced when strontium concentrations are greater than about 1,000 ug/L. As dissolved oxygen concentrations and pH levels change dramatically over 24-h cycles in hypertrophic waters, metals are mobilized from sediments and the balance of oxidation states change. Whether strontium acts as a buffer (of some sort) or simply a proxy for where more malignant metals (e.g., manganese) or metalloids (i.e., arsenic) are less abundant is unknown (Figure 41-c). The eutrophic Big Darby Creek and hypertrophic Scioto River are relatively rich in strontium and poor in manganese (Figure 41-a).

[12] Nutrient and organic enrichment being two sides of the same coin has been extensively discussed elsewhere.
[13] A similar pattern was evident with barium and the ICI, see the Supplemental Information section at the end of this document.
[14] Pheophytin and chlorophyll are typically highly correlated, but pheophytin tends to show stronger correlation to oxygen demand, likely because it represents both the living (i.e., correlated with chlorophyll) and senescent fraction of the phytoplankton (or periphyton) community.

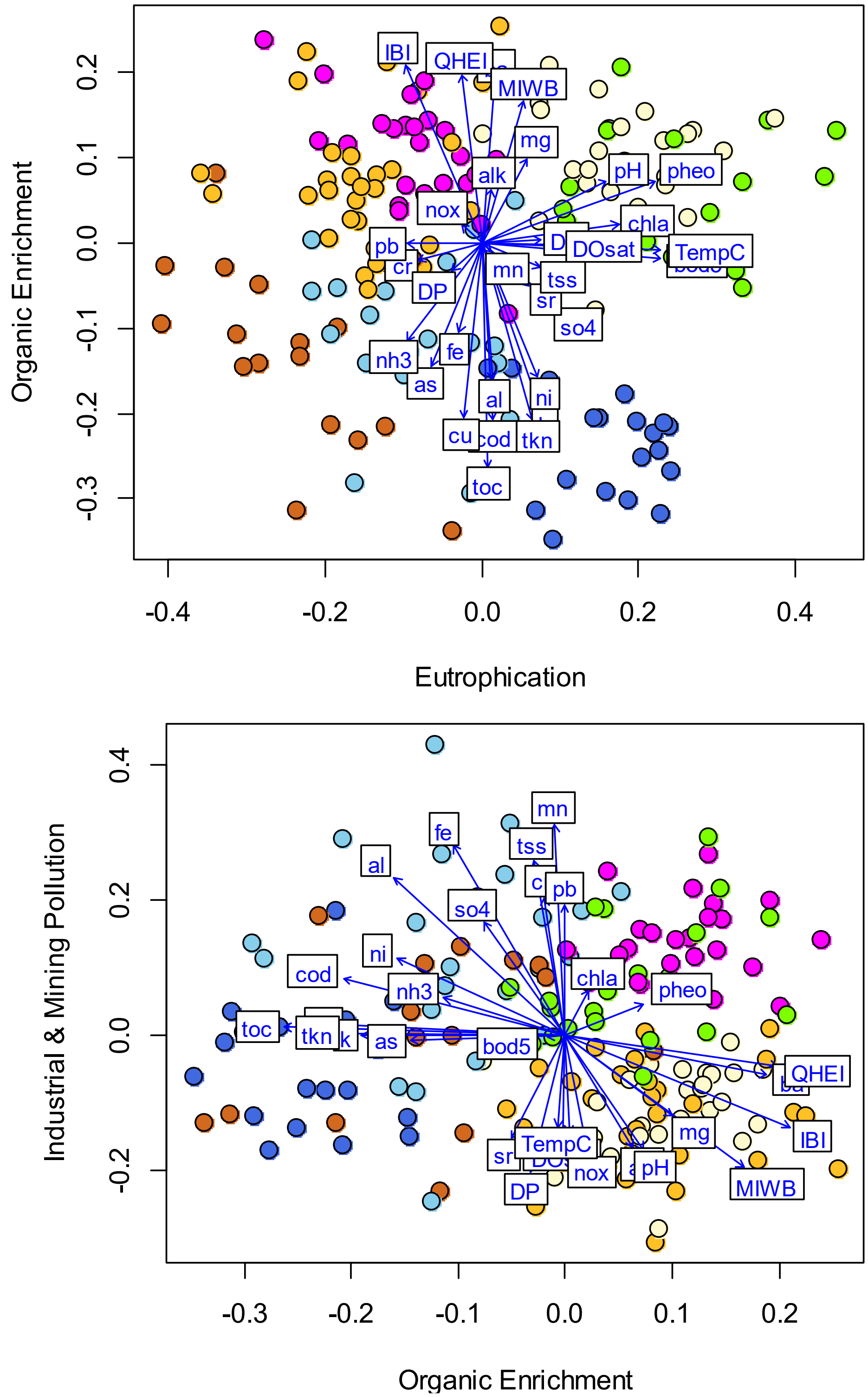


Figure 37 - Large river survey sites plotted in ordination space based on fish assemblages.

Environmental measures that correlate with the ordination axes are shown. The length and direction of the arrow indicates the strength of association and correspondence to an axis. The axis labels are rubrics denoting the overall gradient influencing the fish community (i.e., note the polar positions of IBI and Kjeldahl nitrogen [tkn] along the axis labeled organic enrichment).

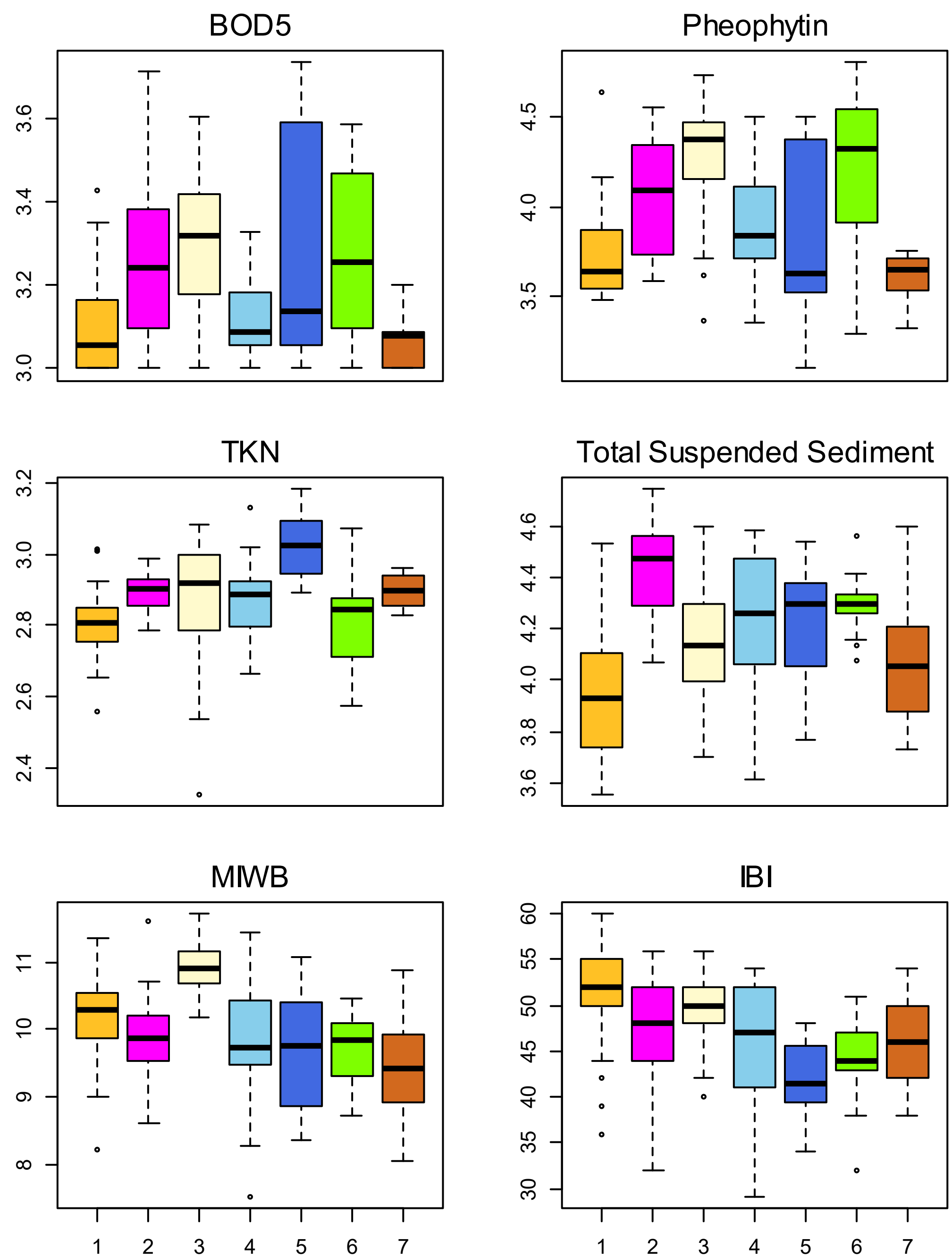


Figure 38 - Distributions of selected water quality parameters and fish index scores by site groupings based on hierarchical clustering.

Rivers within site groups are generally as follows: 1 - upper GMR, Stillwater, Big Darby; 2 - Upper Muskingum, Tuscarawas, Walhonding, Mohican, and Killbuck; 3 - Lower Scioto, LMR and lower GMR; 4 - upper Scioto, Sandusky, Hocking, Licking, and Wills; 5 - Maumee, Auglaize, and Blanchard; 6 - Lower Muskingum; 7 - Grand, Mahoning, Cuyahoga.

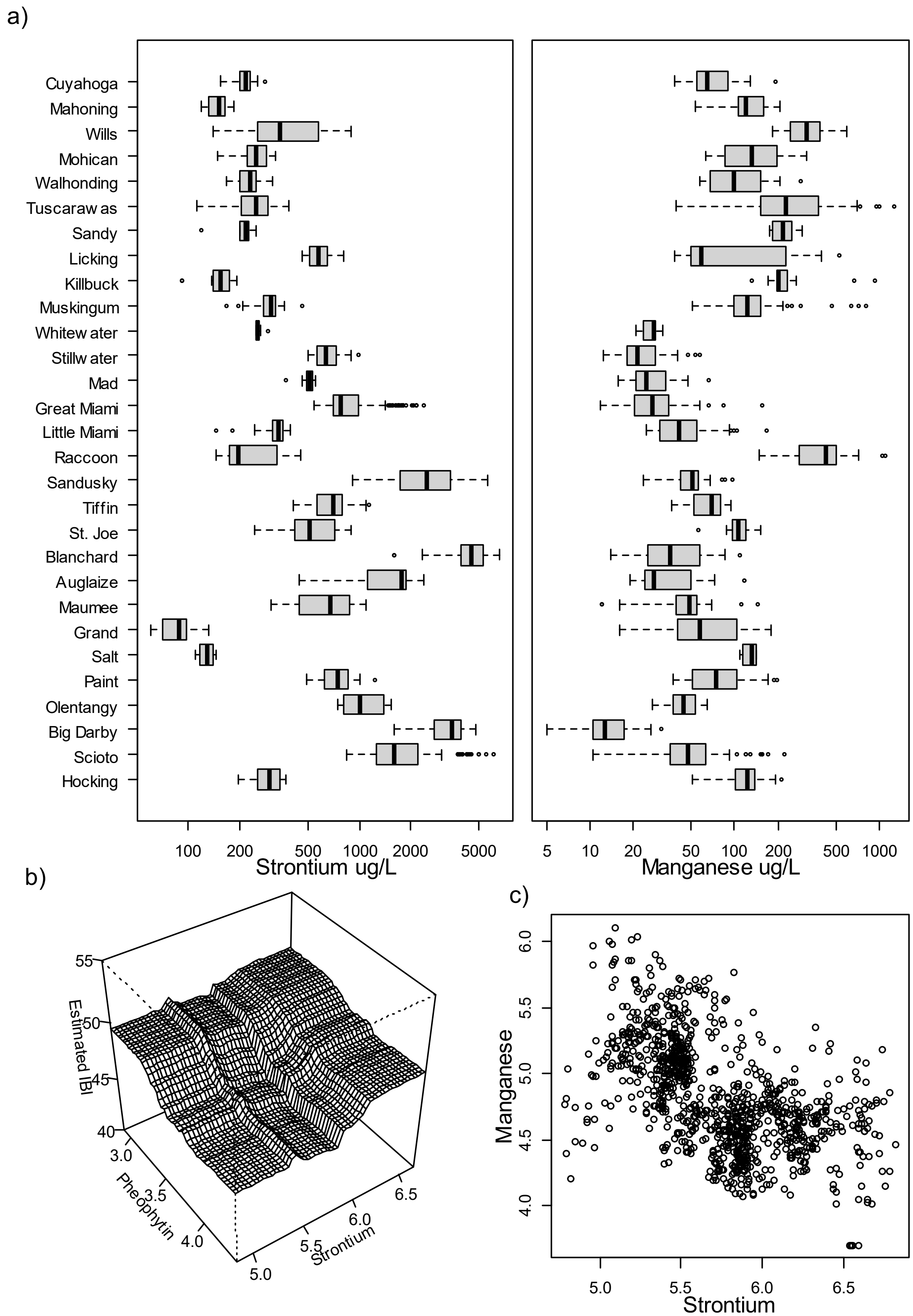


Figure 39 - Sensitivity to the effects of eutrophication based on parent geology.

a) distributions of strontium and manganese by river; b) the modeled relationship between pheophytin, strontium, and fish IBI scores; and c) the relationship between strontium and manganese.

Table 11 - Large river sampling sites with fish index scores and respective narrative ratings.

Large river sampling sites with fish index scores and respective narrative ratings. Where ratings are less than optimal, the causative stressor is noted. Note that because index scores are now so distributed toward the high end of the respective scoring ranges, narratives were adjusted to better reflect the distributions at the high end.

STORET	RM	DA	ALU	IBI	MIWB	IBI Narrative	MIWb Narrative	Stressor
HOCKING RIVER (01-001-000)								
J02W01	68.33	510	WWH	52	10.4	Excellent	Excellent	
J02K06	60.76	562	WWH	48	9.6	Excellent	Excellent	
J02K04	52.8	577	WWH	48	9.7	Excellent	Excellent	
J02P23	44	721	WWH	46	9.7	Good	Excellent	
J02S15	33.03	942	WWH	46	10.2	Good	Excellent	
J03P15	20.6	982	WWH	44	10.2	Good	Excellent	
J03S10	13.56	1141	WWH	38	8.8	Marginal	Good	Eutrophication
SCIOTO RIVER (02-001-000)								
V02W23	175.8	526	WWH	44	8.4	Good	Marginal	Organic Enrichment
V02P15	163.8	660	WWH	46	9.9	Good	Excellent	
201823	157.1	764	WWH	48	9.5	Excellent	Good	
V03P30	145.6	990	WWH	46	9.8	Good	Excellent	
V03W25	136.5	1049	WWH	48	9.7	Excellent	Excellent	
600860	129.5	1617	WWH	50	10.9	Excellent	Excellent	
600810	119.9	1697	WWH	52	11.2	Excellent	Superior	
600910	109.4	2311	WWH	50	10.9	Excellent	Excellent	
600960	99.82	3217	WWH	52	11.1	Excellent	Superior	
201818	94.2	3242	WWH	54	10.8	Excellent	Excellent	
600940	86.4	3348	WWH	45	10.4	Good	Excellent	Eutrophication
201813	77.4	3828	WWH	50	10.9	Excellent	Excellent	
V13S09	67.82	3853	WWH	48	10.8	Excellent	Excellent	
600770	56.17	5131	WWH	52	11.3	Excellent	Superior	
201807	40	5750	WWH	50	10.9	Excellent	Excellent	
201805	33	5837	WWH	48	10.9	Excellent	Excellent	
V15P15	24.5	6086	WWH	48	10.2	Excellent	Excellent	
V15K02	14.67	6174	WWH	46	9.8	Good	Excellent	
V15W01	5	6479	WWH	48	9.9	Excellent	Excellent	
BIG DARBY CREEK (02-200-000)								
V07S03	23.75	501	EWH	56	10.9	Superior	Excellent	
601300	13.36	534	EWH	50	11	Excellent	Superior	
600970	3.2	552	EWH	52	10.4	Excellent	Excellent	
OLENTANGY RIVER (02-400-000)								
V04S16	2.7	537	MWH	36	9	Marginal	Good	Urban Stormwater
PAINT CREEK (02-500-000)								
300053	39.14	570	EWH	46	10.5	Good	Excellent	
V10S28	31.68	773	EWH	54	11.4	Excellent	Superior	

STORET	RM	DA	ALU	IBI	MIWB	IBI Narrative	MIWb Narrative	Stressor
304031	23.5	827	EWH	46	10.5	Good	Excellent	
V10K17	8.9	895	EWH	48	10.8	Excellent	Excellent	
V10W12	1.2	1143	WWH	42	10.6	Good	Excellent	Eutrophication
SALT CREEK (02-600-000)								
V11G02	1.38	551	EWH	50	11.6	Excellent	Superior	
GRAND RIVER (03-001-000)								
G02G15	40.1	522	EWH	50	9.1	Excellent	Good	
502510	22.46	581	EWH	48	9.9	Excellent	Excellent	
G02W14	13.7	630	EWH	54	10.8	Excellent	Excellent	
G02S13	6.1	687	EWH	52	10.2	Excellent	Excellent	
MAUMEE RIVER (04-001-000)								
P06K10	107.1	2119	WWH	42	8.8	Good	Good	
201868	99	2129	WWH	42	9.7	Good	Excellent	
P06S08	91.48	2134	WWH	36	8.6	Marginal	Good	Organic Enrichment
P06K06	85.26	2203	WWH	40	8.4	Good	Marginal	Organic Enrichment
P06S07	76.15	2292	WWH	36	8.8	Marginal	Good	Organic Enrichment
201858	58.5	5548	WWH	48	10.4	Excellent	Excellent	
P09P02	44.35	5681	MWH	39	9.3	Marginal	Good	Organic Enrichment
P11K33	31.64	6058	WWH	42	11.1	Good	Superior	
P11K31	26.7	6264	WWH	40	10.5	Good	Excellent	
500080	20.68	6330	WWH	42	10.7	Good	Excellent	
301740	16.52	6340	WWH	46	10	Good	Excellent	
AUGLAIZE RIVER (04-100-000)								
500110	28.5	719	WWH	46	11	Good	Superior	
P06S10	14.94	2041	MWH	38	10.2	Marginal	Excellent	Organic Enrichment
500290	4.14	2330	WWH	41	10.2	Good	Excellent	
BLANCHARD RIVER (04-160-000)								
P05S03	35.24	508	WWH	47	9.9	Good	Excellent	
500100	28.88	624	WWH	45	9.5	Good	Good	
P05S01	13.37	704	WWH	40	8.9	Good	Good	
ST. JOSEPH RIVER (04-400-000)								
510220	42.34	609	WWH	48	9.5	Excellent	Good	
TIFFIN RIVER (04-600-000)								
P07K01	14	562	WWH	40	9.5	Good	Good	
500160	0.89	775	MWH	34	8.4	Fair	Marginal	Sediment
SANDUSKY RIVER (05-001-000)								
U03G01	65.01	655	WWH	52	9.8	Excellent	Excellent	
U04S29	57.34	760	WWH	52	9.9	Excellent	Excellent	
U04S28	41.84	964	WWH	54	10.5	Excellent	Excellent	
500910	30.85	1047	WWH	54	11.4	Excellent	Superior	
U04Q06	23	1073	WWH	54	10.4	Excellent	Excellent	

STORET	RM	DA	ALU	IBI	MIWB	IBI Narrative	MIWb Narrative	Stressor
U04S23	17.7	1255	WWH	46	10.5	Good	Excellent	
RACCOON CREEK (09-500-000)								
W03S44	35.61	542	WWH	49	9.5	Excellent	Good	
601400	29.2	586	WWH	50	9.8	Excellent	Excellent	
303503	22	615	WWH	51	9.9	Excellent	Excellent	
W03S24	10.2	648	WWH	38	8.7	Marginal	Good	Mining; Eutrophication
LITTLE MIAMI RIVER (11-001-000)								
M05K01	50.25	658	EWH	54	11.4	Excellent	Superior	
M05S12	43.76	680	EWH	50	11.1	Excellent	Superior	
610520	35.98	964	EWH	52	11.1	Excellent	Superior	
M05W34	24.1	1085	EWH	45	11.5	Good	Superior	Eutrophication
M05P11	13.07	1203	EWH	48	10.3	Excellent	Excellent	
600580	3.5	1744	EWH	46	10.1	Good	Excellent	
GREAT MIAMI RIVER (14-001-000)								
201922	118.5	842	EWH	56	11.2	Superior	Superior	
H05S05	106.1	927	EWH	50	10.3	Excellent	Excellent	
H05S19	98.97	1124	EWH	54	10.5	Excellent	Excellent	
H05W01	91.14	1154	EWH	56	10	Superior	Excellent	
H05K01	81.8	1853	WWH	49	11	Excellent	Excellent	
H09W02	78.85	2587	WWH	52	9.9	Excellent	Excellent	
H09S13	66.9	2711	WWH	52	10.3	Excellent	Excellent	
H09W28	55.14	3117	WWH	54	10.4	Excellent	Excellent	
H09W28	55.14	3117	WWH	52	10.4	Excellent	Excellent	
H09W78	51.24	3137	WWH	50	9.9	Excellent	Excellent	
600330	49.27	3189	WWH	54	10.1	Excellent	Excellent	
600330	49.27	3189	WWH	52	9.8	Excellent	Excellent	
201886	43.6	3278	WWH	50	10.1	Excellent	Excellent	
610090	43.23	3280	WWH	42	10.2	Good	Excellent	
610090	43.23	3280	WWH	48	9.2	Excellent	Good	
H11W35	34.1	3636	WWH	50	11.7	Excellent	Superior	
H11W35	34.1	3636	WWH	56	10.8	Superior	Excellent	
H11C01	24.55	3799	WWH	46	10.3	Good	Excellent	
H11C01	24.55	3799	WWH	32	9.1	Fair	Good	Eutrophication
H11W20	15.49	3838	WWH	40	10.5	Good	Excellent	
H11W20	15.49	3838	WWH	44	10.4	Good	Excellent	
H11K14	9.5	3872	WWH	48	11	Excellent	Excellent	
MAD RIVER (14-100-000)								
H04P09	17.48	527	WWH	50	10.1	Excellent	Excellent	
H04S03	8.7	616	WWH	44	9.8	Good	Excellent	
H04P23	0.28	657	WWH	52	9.7	Excellent	Excellent	
STILLWATER RIVER (14-200-000)								

STORET	RM	DA	ALU	IBI	MIWB	IBI Narrative	MIWb Narrative	Stressor
H06P03	27.86	503	EWH	60	10.7	Superior	Excellent	
H06P07	23.44	523	EWH	58	10.6	Superior	Excellent	
H06P09	17.45	602	EWH	56	10.9	Superior	Excellent	
H06S11	11.39	645	EWH	52	9.8	Excellent	Excellent	
H06W30	5.78	660	EWH	56	10.5	Superior	Excellent	
H06K01	1.5	674	EWH	56	9.2	Superior	Good	Golden Redhorse[15]
WHITEWATER RIVER (14-300-000)								
H11W65	3.8	1384	EWH	52	11.4	Excellent	Superior	
MUSKINGUM RIVER (17-001-000)								
300146	110.7	4852	WWH	46	9.5	Good	Good	
611740	108.3	4861	WWH	48	9.9	Excellent	Excellent	
611740	108.3	4861	WWH	54	10.2	Excellent	Excellent	
R11W03	101.8	4883	WWH	47	9.5	Excellent	Good	
611750	92	5993	WWH	48	9.6	Excellent	Good	
R11S12	84.7	6042	WWH	52	10.3	Excellent	Excellent	
R16P06	75.67	6850	WWH	42	9.1	Good	Good	
R16P08	67.48	7196	WWH	44	10.1	Good	Excellent	
R16S28	56.4	7386	WWH	44	8.9	Good	Good	
R16S39	48.81	7422	WWH	48	10.2	Excellent	Excellent	
R16S06	39.3	7457	WWH	44	9.7	Good	Excellent	
R16S20	33.5	7470	WWH	44	9.6	Good	Good	
R19K07	24.8	7713	WWH	43	9.3	Good	Good	
R19K05	14	7995	WWH	40	10	Good	Excellent	
R19K02	5.7	8035	WWH	47	10	Good	Excellent	
KILLBUCK CREEK (17-150-000)								
R04S02	18.36	503	WWH	44	9.2	Good	Good	
203603	13.28	581	WWH	40	9	Good	Good	
203602	2.1	599	WWH	48	9.4	Excellent	Good	
LICKING RIVER (17-200-000)								
601770	26.75	537	WWH	41	10.4	Good	Excellent	
601770	26.75	537	WWH	40	10.6	Good	Excellent	
603300	18.87	672	WWH	43	9.9	Good	Excellent	
R13S27	3.68	753	WWH	47	11.6	Good	Superior	
SANDY CREEK (17-450-000)								
R07S71	0.57	504	WWH	44	10	Good	Excellent	
TUSCARAWAS RIVER (17-500-000)								
R06W79	89	518	WWH	52	9.1	Excellent	Good	
R06A02	78.16	574	WWH	52	9.6	Excellent	Excellent	
R06P75	73.67	586	WWH	39	8.7	Marginal	Good	Industrial Legacy
R10K18	63.2	1404	WWH	46	10.9	Good	Excellent	

[15] The great abundance of golden redhorse reduced the evenness component of the MIWb

STORET	RM	DA	ALU	IBI	MIWB	IBI Narrative	MIWb Narrative	Stressor
R10K12	52.3	1816	WWH	44	10.2	Good	Excellent	
R10K10	44.5	2364	EWH	56	10.7	Superior	Excellent	
R10G02	38.68	2381	EWH	52	10	Excellent	Excellent	
611790	21.17	2443	EWH	56	10.1	Superior	Excellent	
R10S11	15.25	2480	EWH	51	10.2	Excellent	Excellent	
601840	10.73	2566	EWH	48	9.8	Excellent	Excellent	
611730	0.3	2596	EWH	52	9.9	Excellent	Excellent	
WALHONDING RIVER (17-600-000)								
601910	15.73	1505	EWH	52	10.4	Excellent	Excellent	
300288	8.81	1572	EWH	32	9.1	Fair	Good	Sediment & enrichment
R04S35	7.54	1575	EWH	52	10	Excellent	Excellent	
R04W27	0.76	2255	EWH	44	9.7	Good	Excellent	
MOHICAN RIVER (17-700-000)								
300286	27	573	EWH	47	9.8	Good	Excellent	
601870	16.92	948	EWH	45	9.7	Good	Excellent	
304208	11.8	966	EWH	40	8.3	Good	Marginal	
200636	11.5	967	EWH	54	10.7	Excellent	Excellent	
300284	6.53	987.7	EWH	38	8.6	Marginal	Good	Sediment & enrichment
200634	0.45	998	EWH	39	8.2	Marginal	Marginal	Sediment & enrichment
WILLS CREEK (17-800-000)								
R18S01	46.57	659	WWH	30	7.5	Fair	Fair	Sediment (mining)
R18S22	37.74	672	WWH	36	9.2	Marginal	Good	Sediment (mining)
302624	18.54	770.5	WWH	29	8.3	Fair	Marginal	Sediment (mining)
611770	7.04	842	WWH	40	9.6	Good	Excellent	
MAHONING RIVER (18-001-000)								
N03K31	36.2	606	WWH	48	9.4	Excellent	Good	
N03S56	26.36	880	WWH	40	9.7	Good	Excellent	
N03W21	17.63	1017	WWH	42	8.1	Good	Marginal	Industrial Legacy
602300	12.42	1074	WWH	46	9.3	Good	Good	
N03S51	11.43	1075	WWH	50	8.8	Excellent	Good	
CUYAHOGA RIVER (19-001-000)								
F01S13	24.1	555	WWH	38	8.5	Marginal	Marginal	Industrial Legacy
F01S11	15.61	698	WWH	42	9.4	Good	Good	
F01S09	9.7	744	WWH	38	8.9	Marginal	Good	Industrial Legacy

Recent Biological Conditions - Macroinvertebrate Communities

The overall condition of macroinvertebrate communities assessed during the Large River survey is shown graphically in Figure 42. The distribution of ICI scores is overwhelmingly skewed toward excellent scores. In terms of the 1,371 assessed river miles, 852 where in excellent or better condition, 313 were in good or very good condition, 68 were in marginal condition, and 138 were considered fair. Eutrophication, organic enrichment, marginal habitat, and metals were the stressors observed to limit the macroinvertebrate community. Eutrophication was the most pervasive stressor, and in some cases resulted in overt impairment, otherwise it represents an almost systemic drag on our large rivers. The juxtaposition between widespread eutrophication and excellent ICI scores may seem paradoxical; however, when considered in light of the fact that some amount of enrichment is stimulatory, but too much is deleterious, the paradox is largely resolved. A structural equation model illustrates the point (Figure 43).

The effect of eutrophication on the macroinvertebrate community also appears to be episodic and transitory. This is evident in the results from five sites in the lower Great Miami River, where in 2020, macroinvertebrate scores at those sites were compromised by the effects from over-enrichment. Those five sites formed their own cluster group and were positioned in the eutrophic-organic enrichment quadrant in Figure 44 (as the dark blue points in the lower left). In 2021, those same sites were reassessed, and all showed remarkable improvement coincidental with lower stress from eutrophication, and were reclassified to group 1 (the red points in Figure 44); a group characterized by modest enrichment.

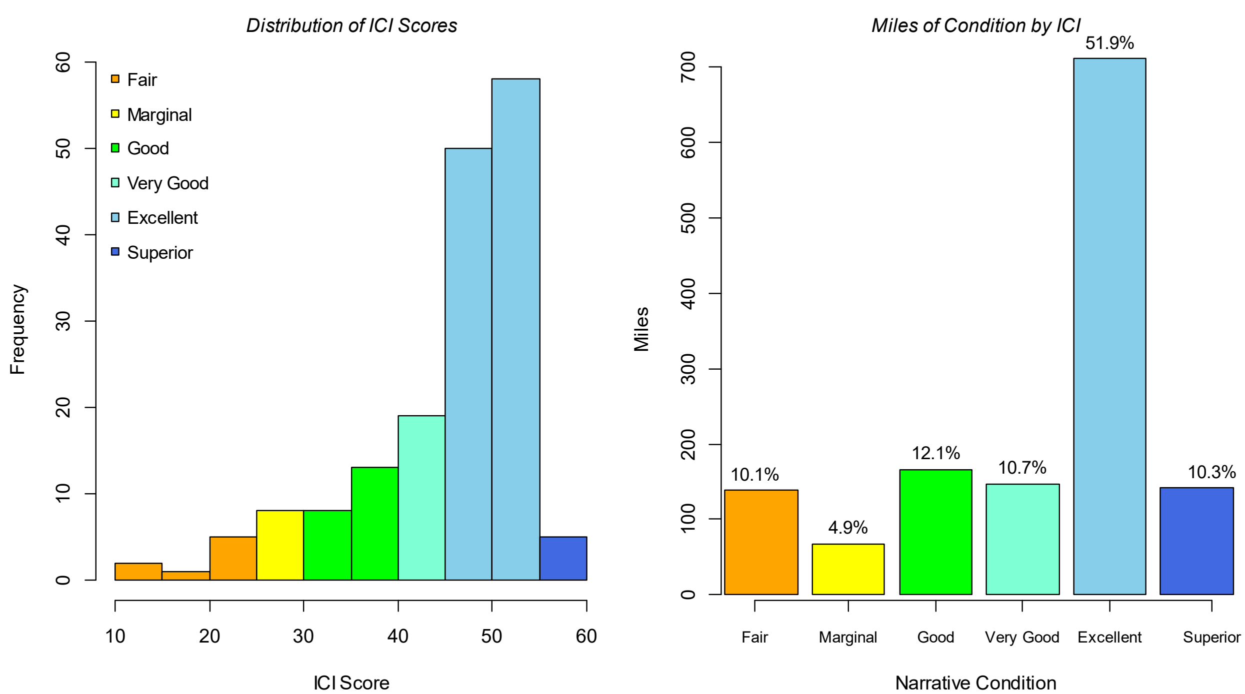


Figure 40 - Distributions of ICI scores color-coded by narrative class, and the number of assessed miles grouped by and color-coded to narrative condition class.

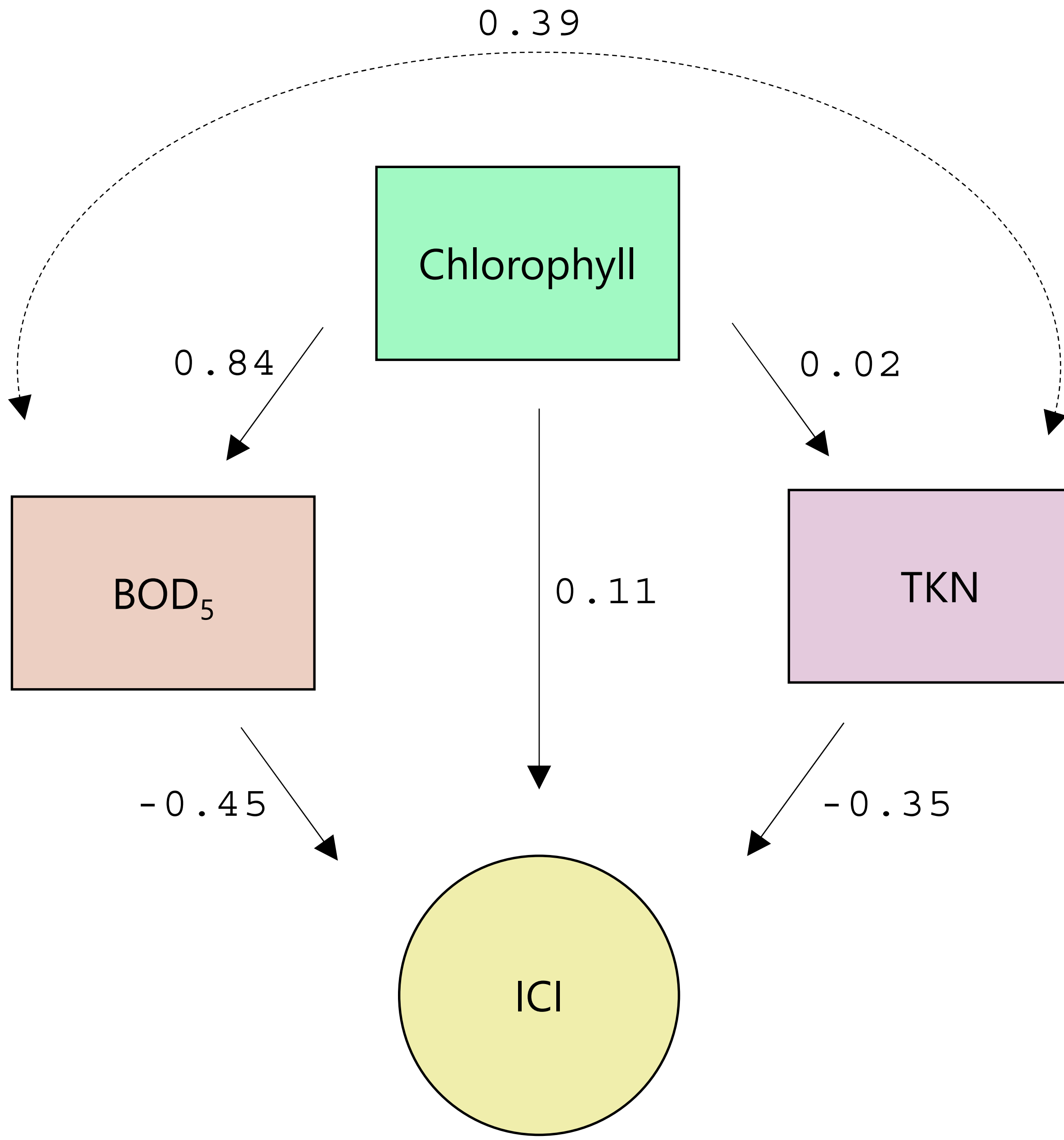


Figure 41 - A structural equation model linking ICI scores to BOD5, TKN and sestonic chlorophyll concentrations.

The numbers next to the arrows are standardized coefficients and can be interpreted as showing how much an increase in a causal variable causes an increase (or decrease if the associated sign is negative) in a response variable in terms of standard deviations. For example, a one standard deviation increase in chlorophyll results in a 0.84 standard deviation increase in BOD5, and a one standard deviation increase in BOD5 results in a 0.45 standard deviation decrease in ICI scores. A stimulatory effect of chlorophyll on the macroinvertebrate community is suggested by the positive sign on the path coefficient linking chlorophyll to the ICI. The stippled, double-headed arrow shows that BOD5 and TKN are correlated (or technically, have shared error variance). The model χ^2 was vanishingly small.

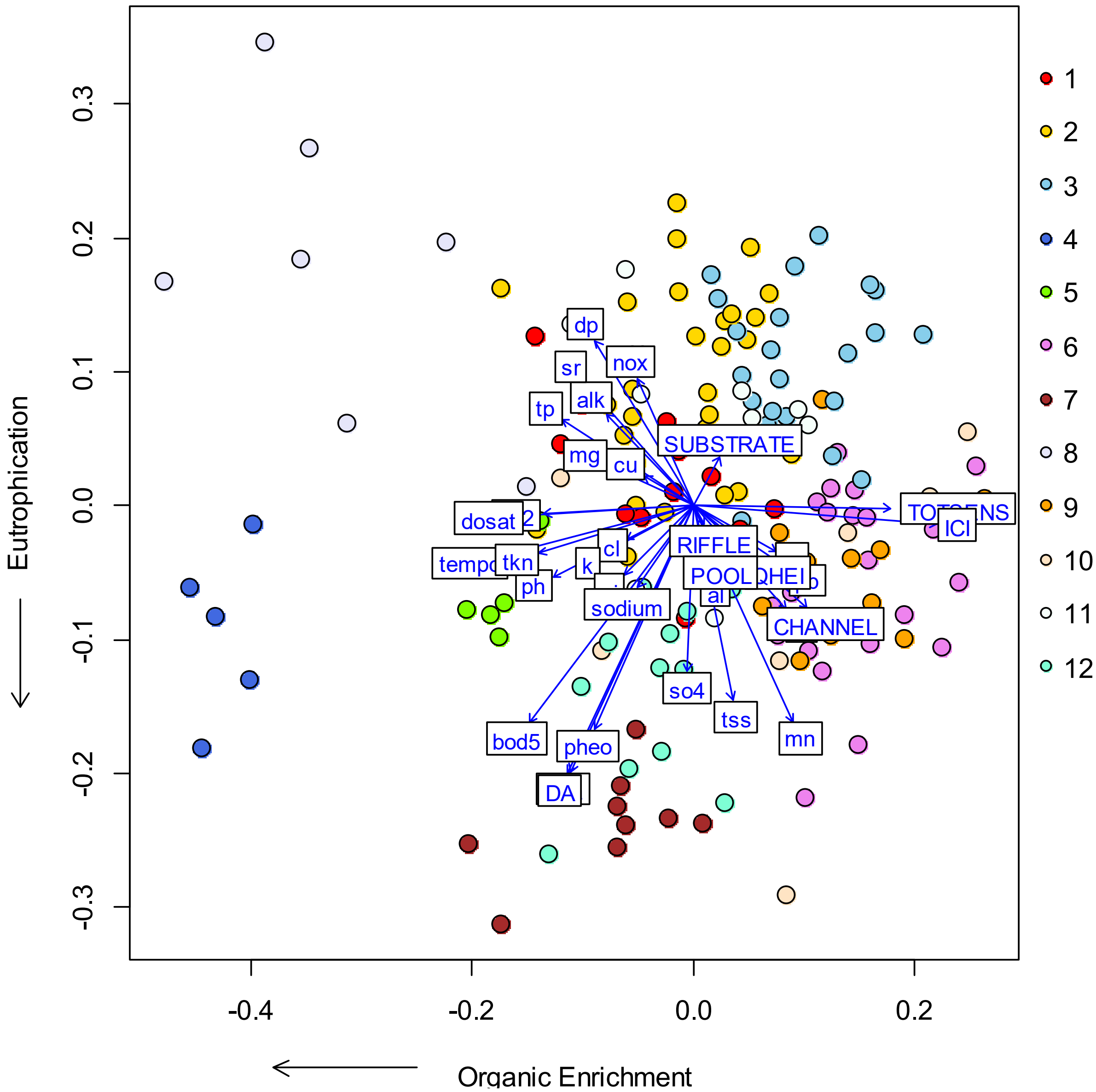


Figure 42 - Macroinvertebrate sites plotted by non-metric multidimensional scaling scores (the first two axes) performed on the distance matrix generated from large river macroinvertebrate data.

Points are color-coded to groups derived by cluster analysis. The axis labels indicate the dominant environmental gradient suggested by the overlay of environmental variables (from the envfit function in the vegan package in R).

As ever, habitat quality is an important environmental gradient that helps explain the quality of macroinvertebrate assemblages. Mirroring the distribution of ICI scores, QHEI scores were highly skewed toward excellent habitat quality (Figure 45). Rivers or sites making up the left tail were primarily from the Maumee watershed and from Wills Creek. There was also a gradient away from habitat quality towards parameters associated with mining, primarily manganese, aluminum, iron, and sulfate. Sites from Wills Creek and Raccoon Creek aligned with that gradient (Figure 46).

Lastly, elevated metals and wastewater form a significant environmental gradient (Figure 47). Sites that are impacted by this gradient are primarily from the Tuscarawas River (metals), the Cuyahoga River (wastewater), and the Mahoning River (wastewater and metals, the latter especially in the sediments – see Figure 49). In the case of the Tuscarawas River, the elevated metals did not result in a categorical impairment of the macroinvertebrate community; however, the richness of EPT and sensitive taxa was lower than expected given the extant habitat quality. Similarly, the added stress of wastewater and metals did not result in categorical impairment of the macroinvertebrates in either the Cuyahoga or Mahoning Rivers. Again, however, EPT and sensitive taxa richness was suppressed, and in the case of the Mahoning River, the ICI at N03W21 (Campbell Avenue, RM 17.63) was in the range of non-significant departure. In this context, and in light of the documented stressors, the departure should be considered not due to chance or error (i.e., the site is impaired).

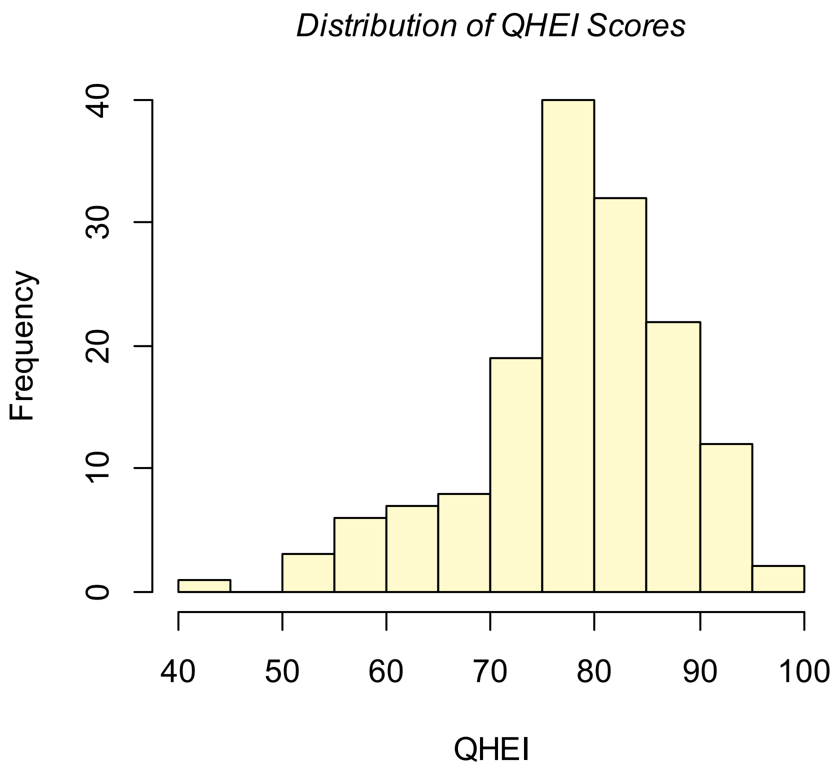


Figure 43 - The distribution of QHEI scores recorded during the Large Rivers survey.

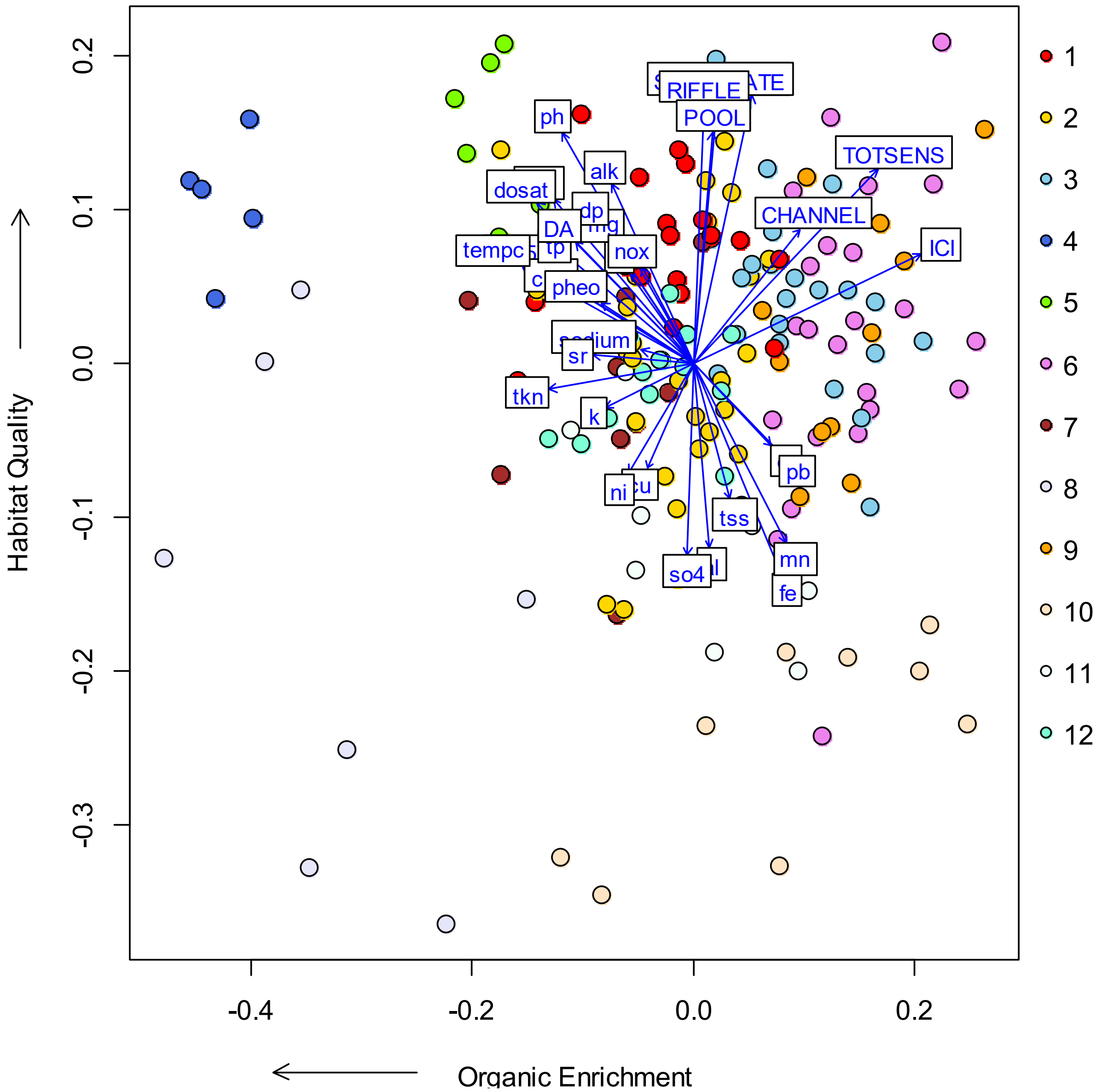


Figure 44 - Macroinvertebrate sites plotted by non-metric multidimensional scaling scores (the first and third axes) performed on the distance matrix generated from large river macroinvertebrate data.

Points are color-coded to groups derived by cluster analysis. The axis labels indicate the dominant environmental gradient suggested by the overlay of environmental variables (from the envfit function in the vegan package in R).

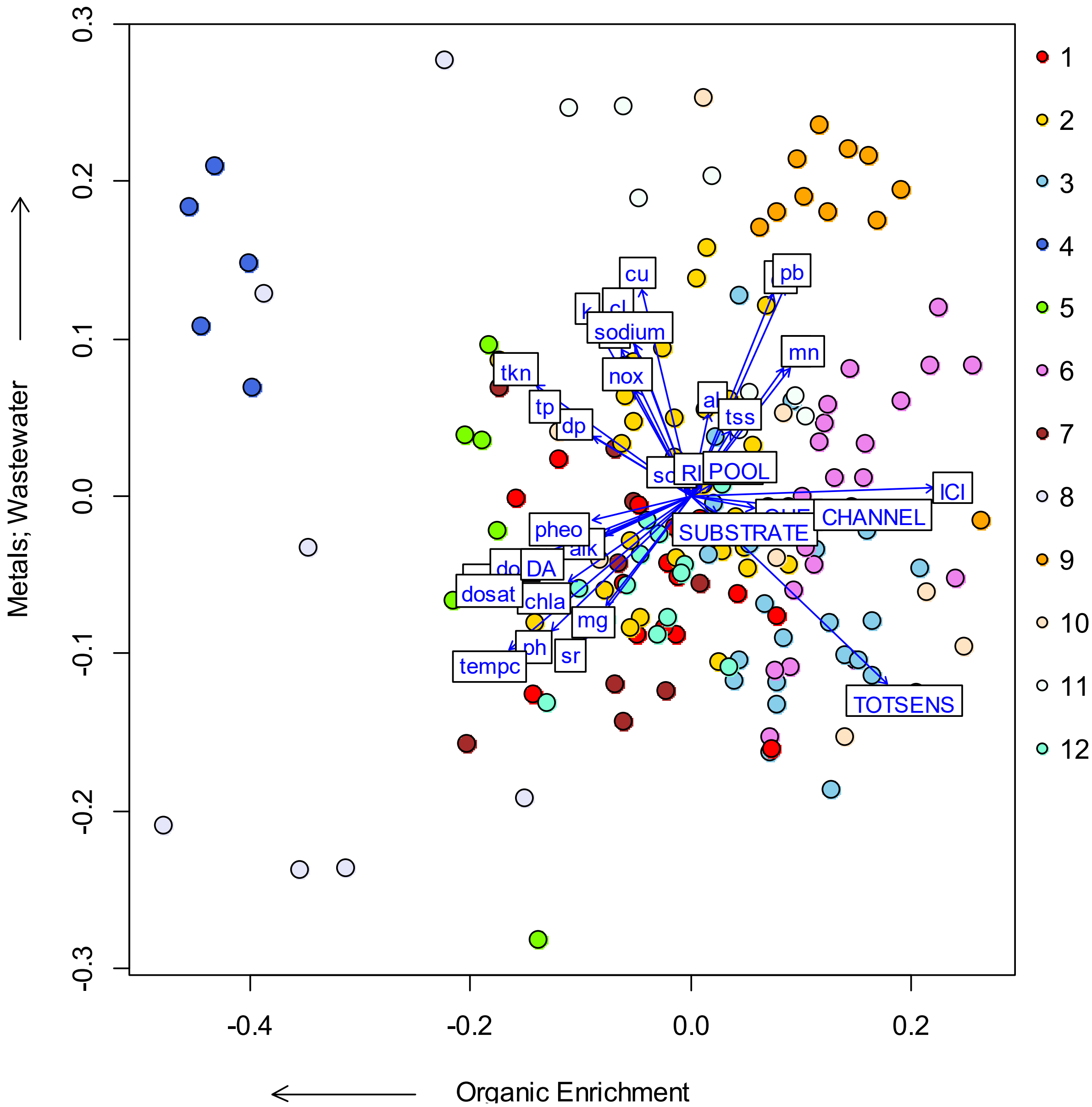


Figure 45 - Macroinvertebrate sites plotted by non-metric multidimensional scaling scores (the first and fourth axes) performed on the distance matrix generated from large river macroinvertebrate data.

Points are color-coded to groups derived by cluster analysis. The axis labels indicate the dominant environmental gradient suggested by the overlay of environmental variables (from the envfit function in the vegan package in R).

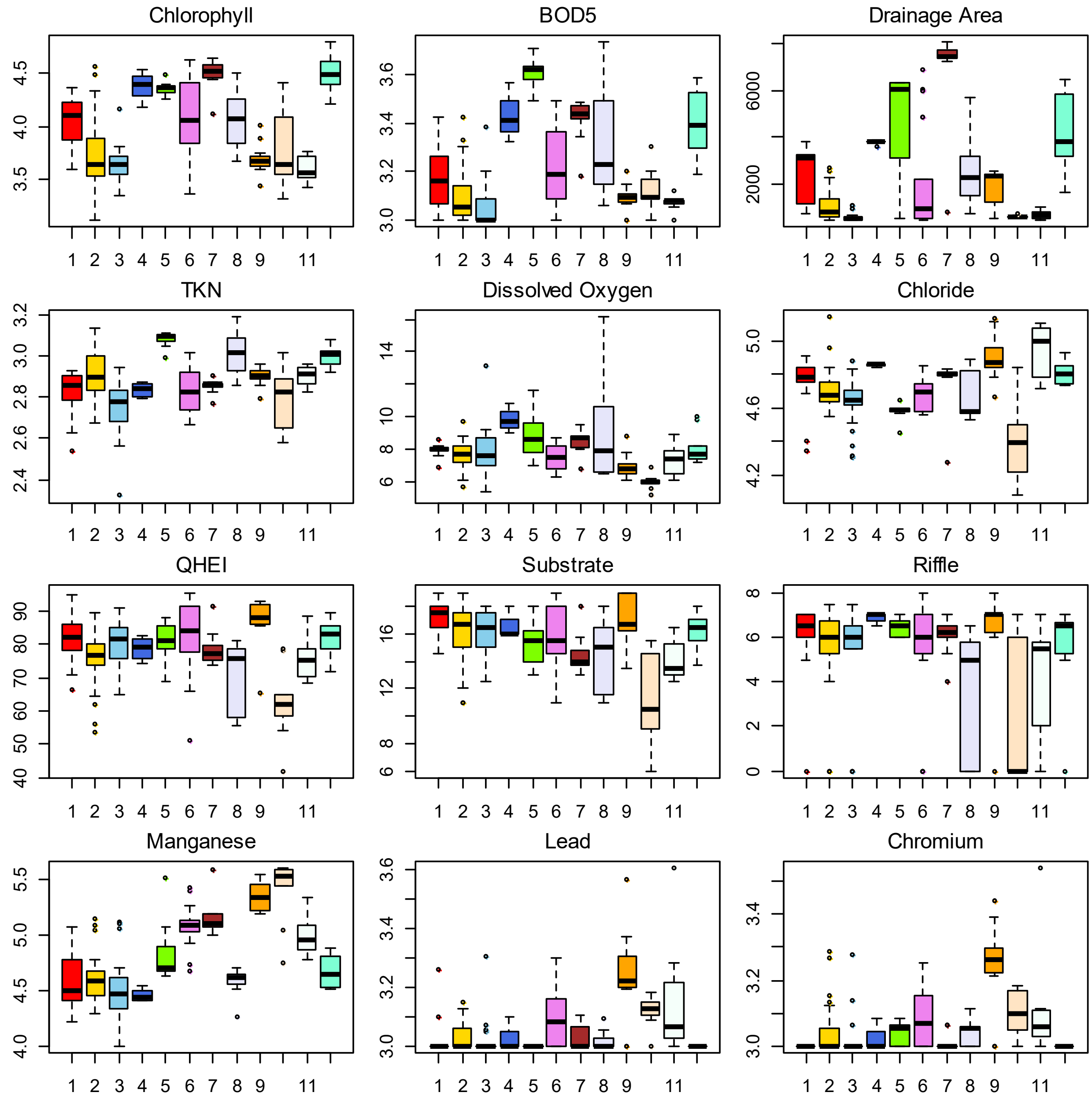


Figure 46 - Distributions of selected environmental variables binned by macroinvertebrate cluster groups.

Table 12 - Macroinvertebrate groups suggested by cluster analysis and brief descriptions of underlying environmental drivers.

Macroinvertebrate groups suggested by cluster analysis and brief descriptions of underlying environmental drivers. Note that the description applies to the group tendency, not necessarily individual sites. See Table 13 for comments on individual sites.

Group	RIVERCODE	RM	DA	EPT	SENS	ICI	QHEI	Comments
Sites in group 1 are characterized as having generally excellent habitat and modest enrichment.								
1	02-500-000	31.68	773	35	43	48	86.8	
1	02-500-000	8.9	895	43	51	54	84.5	
1	02-500-000	1.2	1143	34	37	40	82.3	
1	05-001-000	17.7	1255.3	16	18	26	NA	No water chemistry
1	11-001-000	24.1	1085	30	39	50	90	
1	11-001-000	13.07	1203	25	29	40	85.9	
1	11-001-000	3.5	1744	27	27	46	80.5	
1	14-001-000	81.8	1853	28	32	54	66.5	
1	14-001-000	55.14	3117	36	39	56	79.5	
1	14-001-000	55.14	3117	29	35	54	78.3	
1	14-001-000	49.27	3189	28	32	52	83.3	
1	14-001-000	49.27	3189	35	35	56	76.5	
1	14-001-000	43.6	3278	19	23	34	NA	
1	14-001-000	43.6	3278	25	29	54	95	
1	14-001-000	43.23	3280	26	24	42	71	
1	14-001-000	34.1	3636	26	30	54	79	
1	14-001-000	24.55	3799	22	23	55	78	
1	14-001-000	15.49	3838	31	37	56	89.3	
1	14-300-000	3.8	1384	29	32	56	85.3	
Sites in groups 2 & 3 are characterized as having generally good water quality and excellent habitat.								
2	02-001-000	175.75	526	19	19	46	56	
2	02-001-000	163.8	660	27	28	48	78.3	
2	02-001-000	157.1	764	29	29	48	80	
2	02-001-000	145.57	990	16	22	32	74	
2	02-001-000	136.5	1049	11	19	28	82	
2	02-001-000	129.48	1617	25	30	40	77.8	
2	02-400-000	2.7	537	25	33	40	64.8	
2	04-001-000	107.1	2119	29	34	48	79	
2	04-001-000	99	2129	28	31	55	78.8	
2	04-001-000	91.48	2134	25	28	46	76.5	
2	04-001-000	85.26	2203	28	30	50	80	
2	04-001-000	76.15	2292	28	27	52	62	
2	04-100-000	28.5	719	33	45	46	80.3	
2	04-160-000	35.24	508	28	23	52	76.5	
2	04-160-000	28.88	624	26	25	54	53.8	
2	05-001-000	65.01	656	26	29	40	83	
2	05-001-000	57.34	760.1	21	26	55	83	
2	05-001-000	47.75	774	27	36	55	NA	
2	05-001-000	41.84	964.2	25	28	55	84.3	
2	05-001-000	36.5	1030.9	20	23	55	NA	
2	05-001-000	23	1072	25	28	50	64.3	
2	14-001-000	129.99	541	32	39	50	NA	
2	14-001-000	118.5	842	24	29	50	74.8	
2	14-001-000	118.5	842	33	39	52	74.8	
2	14-001-000	106.1	927	32	37	50	75.5	

Group	RIVERCODE	RM	DA	EPT	SENS	ICI	QHEI	Comments
2	14-001-000	98.97	1124	31	31	44	89.3	
2	14-001-000	78.85	2587	21	22	44	74.5	
2	14-001-000	66.9	2711	27	26	50	74.8	
2	14-100-000	0.28	657	25	26	56	72.8	
2	14-200-000	11.39	645	29	35	42	73	
2	17-500-000	89	518	19	15	55	77.5	
3	02-200-000	23.75	501	34	43	54	84.8	
3	02-200-000	13.36	534	42	52	54	85.8	
3	02-200-000	13.36	534	36	45	54	NA	
3	02-200-000	3.2	552	32	36	52	81.3	
3	02-600-000	1.38	551	32	38	46	75.3	
3	03-001-000	40.1	522	34	39	48	64.8	
3	03-001-000	22.46	581	33	45	46	84	
3	03-001-000	13.7	630	39	54	52	81	
3	03-001-000	6.1	687	36	43	52	78.5	
3	11-001-000	50.25	658	26	28	48	90.8	
3	11-001-000	43.76	680	26	35	54	84	
3	11-001-000	35.98	964	24	33	50	82	
3	11-001-000	35.98	964	30	44	52	82	
3	14-001-000	98.97	1124	36	38	48	89.3	
3	14-001-000	91.14	1154	43	54	52	75.8	
3	14-100-000	17.48	527	34	37	54	81.8	
3	14-100-000	8.7	616	29	29	50	79.3	
3	14-200-000	27.86	503	35	55	42	70	
3	14-200-000	21.5	528	34	42	55	NA	
3	14-200-000	17.45	602	31	39	44	71	
3	14-200-000	5.78	660	45	52	54	89.5	
3	14-200-000	1.5	674	34	40	52	71.5	
3	17-700-000	27	573	29	37	52	87.3	
Sites in groups 4, 5, and 7 are the most eutrophic and tend to have marginal biological quality as a result.								
4	14-001-000	34.1	3636	6	10	22	74.3	
4	14-001-000	24.55	3799	6	7	55	77.5	
4	14-001-000	18.2	3834	7	9	24	NA	
4	14-001-000	15.49	3838	12	12	32	80.3	
4	14-001-000	9.5	3872	9	13	32	82.5	
5	02-500-000	39.14	570	16	12	26	86.8	
5	04-001-000	58.5	5548	18	21	30	78	
5	04-001-000	31.64	6058	18	18	30	79	
5	04-001-000	26.7	6264	22	24	24	83.8	
5	04-001-000	20.68	6330	18	23	40	68.8	
5	04-001-000	16.52	6340	16	22	40	81	
5	17-200-000	3.68	753	20	23	30	88	
7	17-001-000	67.48	7196	30	39	48	91.5	
7	17-001-000	56.4	7386	29	35	42	75	
7	17-001-000	48.81	7422	29	31	42	83	
7	17-001-000	39.3	7457	15	14	28	77.3	
7	17-001-000	33.5	7470	21	30	44	73.5	
7	17-001-000	24.8	7713	25	36	44	75.4	
7	17-001-000	14	7995	17	18	32	79.8	
7	17-001-000	5.7	8035	18	28	36	76.75	
7	17-800-000	7.04	842	19	24	46	77	

Group	RIVERCODE	RM	DA	EPT	SENS	ICI	QHEI	Comments
Sites in group 6 are from the Hocking and Muskingum rivers. These sites tended to have excellent habitat quality and good to excellent macroinvertebrate indicators. Modest eutrophication is evident at some sites.								
6	01-001-000	68.33	510	34	35	55	87.5	
6	01-001-000	59.1	565	31	34	46	NA	
6	01-001-000	52.8	577	28	29	55	66.5	
6	01-001-000	44	721	32	36	55	77	
6	01-001-000	33.03	942	39	36	48	51	
6	01-001-000	20.6	982	25	31	54	84.8	
6	01-001-000	13.56	1141	24	22	55	72.5	
6	17-001-000	108.28	4861	29	35	42	91.5	
6	17-001-000	101.8	4883	34	48	52	91	
6	17-001-000	92	5993	33	37	52	78	
6	17-001-000	84.7	6042	37	45	52	92	
6	17-001-000	75.67	6850	30	32	52	66	
6	17-150-000	18.36	503	28	21	50	75	
6	17-150-000	13.28	581	36	36	54	83.5	
6	17-150-000	2.1	599	38	40	52	79	
6	17-200-000	26.75	537	24	23	52	87	
6	17-200-000	18.87	672	33	33	54	90.5	
6	17-600-000	15.73	1505	39	45	54	84	
6	17-600-000	7.54	1575	38	42	50	91.5	
6	17-600-000	0.76	2255	39	52	50	95.5	
6	17-600-000	0.76	2255	29	31	48	95.5	
6	17-700-000	16.92	948	39	48	48	81.8	
6	17-700-000	6.53	987.7	36	43	48	92	
6	17-700-000	0.45	998	39	48	48	82	
Sites in group 8 tend to have marginal habitat and elevated levels of TKN.								
8	04-001-000	44.35	5681	10	9	14	55.5	
8	04-100-000	14.94	2041	8	4	16	58.5	
8	04-100-000	4.14	2330	9	9	14	78.3	
8	04-600-000	0.86	775	9	6	22	57.5	
8	05-001-000	30.85	1048.2	16	17	32	79	
8	14-001-000	51.24	3137	13	13	28	75.8	
8	14-001-000	43.23	3280	12	11	24	81.3	
Sites in group 9 have excellent habitat, but tend to have elevated levels of metals and lower than expected EPT and sensitive taxa richness.								
9	17-500-000	81.46	556	21	19	48	NA	
9	17-500-000	71.73	1091	27	27	48	NA	
9	17-500-000	63.2	1404	27	32	52	65.5	
9	17-500-000	52.3	1816	24	26	44	85.5	
9	17-500-000	44.5	2364	22	19	48	87	
9	17-500-000	38.68	2381	28	34	52	89	
9	17-500-000	21.17	2443	33	38	52	91	
9	17-500-000	15.25	2480	24	26	50	93	
9	17-500-000	10.73	2566	23	22	55	86.5	
9	17-500-000	0.3	2596	28	30	50	92.5	
9	18-001-000	37.43	602	20	24	42	NA	
Sites in group 10 have marginal habitat and elevated levels of metals. These sites have lower than expected EPT and sensitive taxa richness.								
10	04-160-000	13.37	704	14	10	46	42	
10	04-400-000	42.34	609	15	12	34	65	
10	09-500-000	35.61	542	27	26	42	62	

Group	RIVERCODE	RM	DA	EPT	SENS	ICI	QHEI	Comments
10	09-500-000	29.2	586	23	26	44	63.5	
10	09-500-000	22	615	24	30	48	78.8	
10	09-500-000	10.2	648	30	31	48	78	
10	17-800-000	46.57	659	21	15	46	58.3	
10	17-800-000	37.74	672	22	22	44	54	
10	17-800-000	18.54	770.5	17	12	36	59	
Group 11 sites are characterized by WWTP effluent.								
11	17-450-000	0.57	504	17	13	44	71	
11	18-001-000	26.36	880	19	17	42	68.3	
11	18-001-000	17.63	1017	15	10	32	75	
11	18-001-000	12.42	1074	9	8	38	88.5	
11	19-001-000	24.1	555	23	19	48	80	
11	19-001-000	22.4	559	26	24	55	NA	
11	19-001-000	20.8	583	23	21	55	NA	
11	19-001-000	15.61	698	24	21	48	77.5	
11	19-001-000	9.7	744	21	17	40	70	
Sites in group 12 are highly eutrophic but the macroinvertebrate indicators are generally excellent. However, EPT richness is slightly lower than expected.								
12	02-001-000	119.9	1697	28	37	40	84.5	
12	02-001-000	109.37	2311	26	39	54	85.8	
12	02-001-000	99.82	3217	34	49	48	89.65	
12	02-001-000	97.8	3221	31	35	52	NA	
12	02-001-000	86.4	3348	28	33	50	71.8	
12	02-001-000	79.81	3823	23	26	50	NA	
12	02-001-000	77.4	3828	33	42	50	80	
12	02-001-000	67.82	3853	32	38	50	79.8	
12	02-001-000	56.17	5131	31	33	52	86.5	
12	02-001-000	40	5750	30	38	52	84.5	
12	02-001-000	33	5837	25	34	40	74.5	
12	02-001-000	24.5	6086	30	33	44	84.8	
12	02-001-000	14.67	6174	30	34	55	81.8	
12	02-001-000	5	6479	24	24	52	77.3	
This site on Paint Creek fell out as an outlier because of the number of mussels found at the site.								
	02-500-000	23.5	827	20	32	46	80.5	

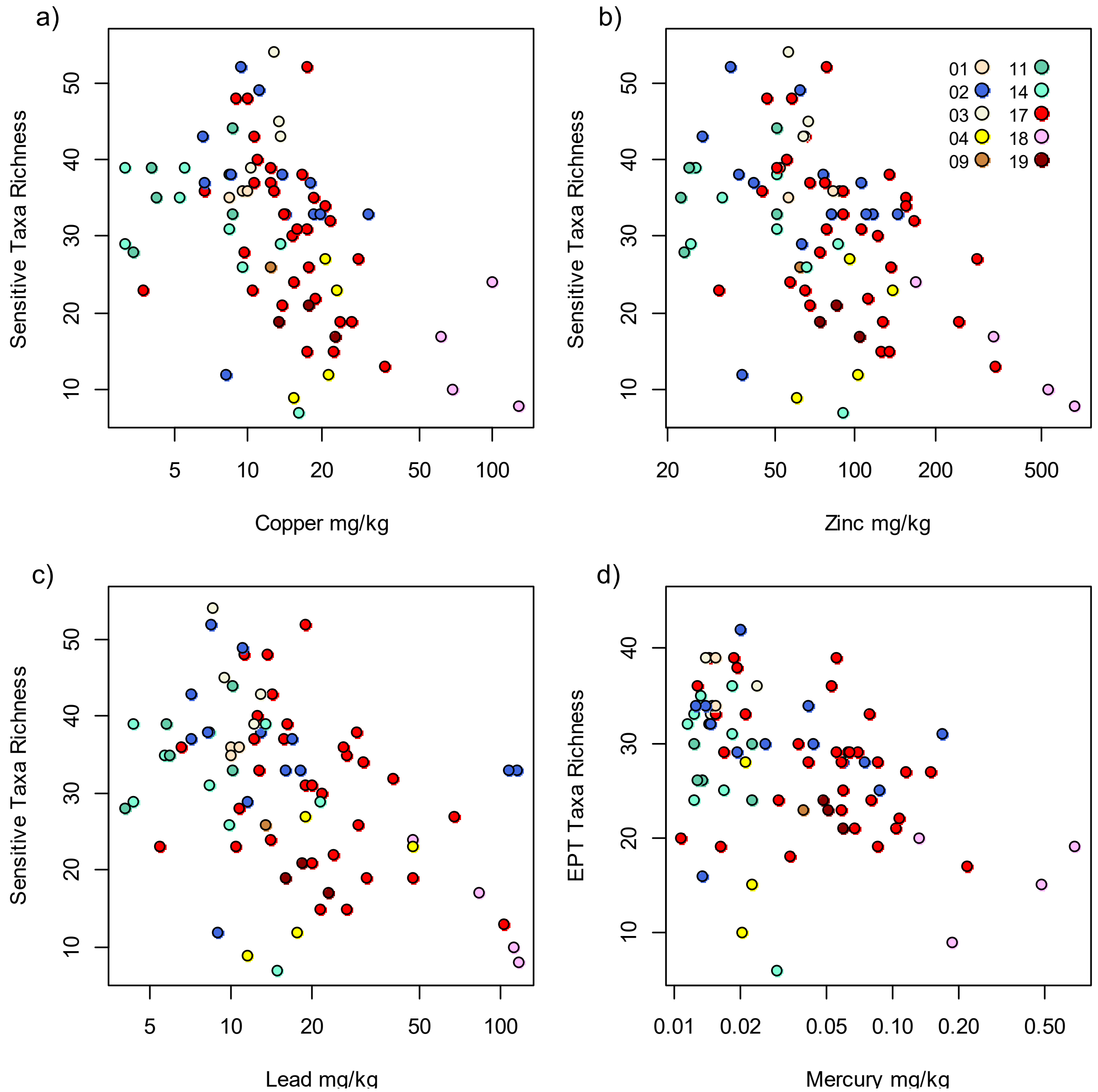


Figure 47 - Relationships between macroinvertebrate indicators and sediment metal concentrations.

a-c) sensitive taxa richness on copper, zinc and lead. d) EPT richness on mercury. Points are color-coded to basin as shown in b).

Table 13 - Macroinvertebrate indicators by river and designated aquatic life use.

ICI scores missing the applicable biocriterion by greater than a 4-point margin are noted with an asterisk; those within the 4-point margin of error are noted with an ns superscript. Comments are provided where the indicators underperformed or failed to meet the biocriterion.

RM	STORET	DA	EPT	Sensitive	ICI	QHEI	Comment/Stressor
Hocking River - WWH 01-001-000							
68.33	J02W01	510	34	35	E	87.5	
59.1	J02S17	565	31	34	46	NA	
52.8	J02K04	577	28	29	E	66.5	
44	J02P23	721	32	36	E	77	
33.03	J02S15	942	39	36	48	51	
20.6	J03P15	982	25	31	54	84.8	
13.56	J03S10	1141	24	22	E	72.5	
Scioto River -WWH 02-001-000							
175.75	V02W23	526	19	19	46	56	
163.8	V02P15	660	27	28	48	78.3	
157.1	201823	764	29	29	48	80	
145.57	V03P30	990	16	22	32^{ns}	74	elevated NH3 & TKN
136.5	V03W25	1049	11	19	28*	82	Water chem is ambiguous
129.48	600860	1617	25	30	40	77.8	
119.9	600810	1697	28	37	40	84.5	
Scioto River -EWH							
109.37	600910	2311	26	39	54	85.8	
99.82	600960	3217	34	49	48	89.65	
97.8	V07S01	3221	31	35	52	NA	
86.4	600940	3348	28	33	50	71.8	
79.81	V13W08	3823	23	26	50	NA	
77.4	201813	3828	33	42	50	80	
67.82	V13S09	3853	32	38	50	79.8	
56.17	600770	5131	31	33	52	86.5	
Scioto River -WWH							
40	201807	5750	30	38	52	84.5	
33	201805	5837	25	34	40	74.5	Eutrophication
24.5	V15P15	6086	30	33	44	84.8	Eutrophication
14.67	V15K02	6174	30	34	E	81.8	
5	V15W01	6479	24	24	52	77.3	
Big Darby Creek - EWH 02-200-000							
23.75	V07S03	501	34	43	54	84.8	
13.36	601300	534	42	52	54	85.8	
13.36	601300	534	36	45	54	NA	
3.2	600970	552	32	36	52	81.3	
Olentangy River - MWH 02-400-000							
2.7	V04S16	537	25	33	40	64.8	
Paint Creek - EWH 02-500-000							
39.14	300053	570	16	12	26*	86.8	Tailwaters
31.68	V10S28	773	35	43	48	86.8	
23.5	304031	827	20	32	46	80.5	
8.9	V10K17	895	43	51	54	84.5	
Paint Creek - EWH							
1.2	V10W12	1143	34	37	40	82.3	
Salt Creek - EWH 02-600-000							
1.38	V11G02	551	32	38	46	75.3	

RM	STORET	DA	EPT	Sensitive	ICI	QHEI	Comment/Stressor
Grand River - EWH 03-001-000							
40.1	G02G15	522	34	39	48	64.8	
22.46	502510	581	33	45	E	84	
13.7	G02W14	630	39	54	52	81	
6.1	G02S13	687	36	43	52	78.5	
Maumee River - WWH 04-001-000							
107.1	P06K10	2119	29	34	48	79	
99	201868	2129	28	31	55	78.8	
91.48	P06S08	2134	25	28	46	76.5	
85.26	P06K06	2203	28	30	50	80	
76.15	P06S07	2292	28	27	52	62	
58.5	201858	5548	18	21	30^{ns}	78	Elevated TKN; Chl, BOD
Maumee River - MWH							
44.35	P09P02	5681	10	9	14	55.5	Elevated TKN; Chl, BOD
Maumee River - WWH							
31.64	P11K33	6058	18	18	30	79	
26.7	P11K31	6264	22	24	E	83.8	Elevated TKN; Chl, BOD
20.68	500080	6330	18	23	40	68.8	
16.52	301740	6340	16	22	40	81	
Auglaize River -WWH 04-100-000							
28.5	500110	719	33	45	46	80.3	
Auglaize River -MWH							
14.94	P06S10	2041	8	4	16	58.5	TKN, BOD
Auglaize River -WWH							
4.14	500290	2330	9	9	14*	78.3	TKN
Blanchard River - WWH 04-160-000							
35.24	P05S03	508	28	23	52	76.5	
28.88	500100	624	26	25	54	53.8	
13.37	P05S01	704	14	10	46	42	
St. Joe River - WWH 04-400-000							
42.34	510220	609	15	12	34^{ns}	65	TKN, TSS, Al, Fe
Tiffin River - MWH 04-600-000							
0.86	500160	775	9	6	22	57.5	
Sandusky River - WWH 05-001-000							
65.01	U03G01	656	26	29	40	83	
57.34	U04S29	760.1	21	26	E	83	
47.75	500830	774	27	36	E	NA	
41.84	U04S28	964.2	25	28	E	84.3	
36.5	500880	1030.9	20	23	E	NA	
30.85	500910	1048.2	16	17	32^{ns}	79	group suggests organic enrichment
23	U04Q06	1072	25	28	50	64.3	
17.7	U04S23	1255.3	16	18	26*	NA	no chem; likely enrichment
Raccoon Creek - EWH 09-500-000							
35.61	W03S44	542	27	26	42^{ns}	62	marginal habitat; manganese
29.2	601400	586	23	26	44^{ns}	63.5	marginal habitat; manganese
22	303503	615	24	30	48	78.8	
10.2	W03S24	648	30	31	48	78	
Little Miami River - EWH 11-001-000							
50.25	M05K01	658	26	28	48	90.8	
43.76	M05S12	680	26	35	54	84	
35.98	610520	964	24	33	50	82	
35.98	610520	964	30	44	52	82	

RM	STORET	DA	EPT	Sensitive	ICI	QHEI	Comment/Stressor
24.1	M05W34	1085	30	39	50	90	
13.07	M05P11	1203	25	29	40*	85.9	Enriched (TKN)
3.5	600580	1744	27	27	46	80.5	
Great Miami River - EWH 14-001-000							
129.99	H02P12	541	32	39	50	NA	
118.5	201922	842	24	29	50	74.8	
118.5	201922	842	33	39	52	74.8	
106.1	H05S05	927	32	37	50	75.5	
98.97	H05S19	1124	31	31	44^{ns}	89.3	
98.97	H05S19	1124	36	38	48	89.3	
91.14	H05W01	1154	43	54	52	75.8	
Great Miami River - WWH							
81.8	H05K01	1853	28	32	54	66.5	
78.85	H09W02	2587	21	22	44	74.5	
66.9	H09S13	2711	27	26	50	74.8	
55.14	H09W28	3117	36	39	56	79.5	
55.14	H09W28	3117	29	35	54	78.3	
51.24	H09W78	3137	13	13	28*	75.8	Eutrophication
49.27	600330	3189	28	32	52	83.3	
49.27	600330	3189	35	35	56	76.5	
43.6	201886	3278	19	23	34^{ns}	95	Eutrophication
43.6	201886	3278	25	29	54	95	
43.23	610090	3280	26	24	42	71	
43.23	610090	3280	12	11	24*	81.3	Eutrophication
34.1	H11W35	3636	26	30	54	79	
34.1	H11W35	3636	6	10	22*	74.3	Eutrophication
24.55	H11C01	3799	22	23	E	78	
24.55	H11C01	3799	6	7	F	77.5	Eutrphiciation
18.2	H11K17	3834	7	9	24*	NA	Eutrophication
15.49	H11W20	3838	31	37	56	89.3	
15.49	H11W20	3838	12	12	32^{ns}	80.3	Eutrophication
9.5	H11K14	3872	9	13	32^{ns}	82.5	Eutrophication
Mad River - WWH 14-100-000							
17.48	H04P09	527	34	37	54	81.8	
8.7	H04S03	616	29	29	50	79.3	
0.28	H04P23	657	25	26	56	72.8	
Stillwater River - EWH 14-200-000							
27.86	H06P03	503	35	55	42^{ns}	70	chemistry ambiguous, EPT and sensitive richness suggest ICI ns is due to error
21.5	H06G04	528	34	42	E	NA	
17.45	H06P09	602	31	39	44	71	
11.39	H06S11	645	29	35	42^{ns}	73	NH3
5.78	H06W30	660	45	52	54	89.5	
1.5	H06K01	674	34	40	52	71.5	
Whitewater River - EWH 14-300-000							
3.8	H11W65	1384	29	32	56	85.3	
Muskingum River - WWH 17-001-000							
108.28	611740	4861	29	35	42	91.5	
101.8	R11W03	4883	34	48	52	91	
92	611750	5993	33	37	52	78	
84.7	R11S12	6042	37	45	52	92	

RM	STORET	DA	EPT	Sensitive	ICI	QHEI	Comment/Stressor
75.67	R16P06	6850	30	32	52	66	
67.48	R16P08	7196	30	39	48	91.5	
56.4	R16S28	7386	29	35	42	75	
48.81	R16S39	7422	29	31	42	83	
39.3	R16S06	7457	15	14	28*	77.3	Eutrophication
33.5	R16S20	7470	21	30	44	73.5	
24.8	R19K07	7713	25	36	44	75.4	
14	R19K05	7995	17	18	32^{ns}	79.8	Eutrophication
5.7	R19K02	8035	18	28	36	76.75	
Killbuck Creek - WWH 17-150-000							
18.36	R04S02	503	28	21	50	75	
13.28	203603	581	36	36	54	83.5	
2.1	203602	599	38	40	52	79	
Licking River - WWH 17-200-000							
26.75	601770	537	24	23	52	87	
18.87	603300	672	33	33	54	90.5	
3.68	R13S27	753	20	23	30*	88	Eutrophication
Sandy Creek - WWH 17-450-000							
0.57	R07S71	504	17	13	44	71	Sediment metals
Tuscarawas River - WWH 17-500-000							
89	R06W79	518	19	15	55	77.5	
81.46	R06P81	556	21	19	48	NA	
71.73	R06P01	1091	27	27	48	NA	
63.2	R10K18	1404	27	32	52	65.5	
52.3	R10K12	1816	24	26	44	85.5	
Tuscarawas River - EWH							
44.5	R10K10	2364	22	19	48	87	
38.68	R10G02	2381	28	34	52	89	
21.17	611790	2443	33	38	52	91	
15.25	R10S11	2480	24	26	50	93	
10.73	601840	2566	23	22	E	86.5	
0.3	611730	2596	28	30	50	92.5	
Walhonding River - EWH 17-600-000							
15.73	601910	1505	39	45	54	84	
7.54	R04S35	1575	38	42	50	91.5	
0.76	R04W27	2255	39	52	50	95.5	
0.76	R04W27	2255	29	31	48	95.5	
Mohican River - EWH 17-700-000							
27	300286	573	29	37	52	87.3	
16.92	601870	948	39	48	48	81.8	
6.53	300284	987.7	36	43	48	92	
0.45	200634	998	39	48	48	82	
Wills Creek - WWH 17-800-000							
46.57	R18S01	659	21	15	46	58.3	
37.74	R18S22	672	22	22	44	54	
18.54	302624	770.5	17	12	36	59	
7.04	611770	842	19	24	46	77	
Mahoning River - WWH 18-001-000							
37.43	N03W13	602	20	24	42	NA	
26.36	N03S56	880	19	17	42	68.3	
17.63	N03W21	1017	15	10	32^{ns}	75	Sediment metals
12.42	602300	1074	9	8	38	88.5	

RM	STORET	DA	EPT	Sensitive	ICI	QHEI	Comment/Stressor
Cuyahoga River - WWH 19-001-000							
24.1	F01S13	555	23	19	48	80	
22.4	304228	559	26	24	E	NA	
20.8	304227	583	23	21	E	NA	
15.61	F01S11	698	24	21	48	77.5	
9.7	F01S09	744	21	17	40	70	

Trends in Contaminant Concentrations Measured in Fish Tissue

Whole body samples of common carp have been collected for fish tissue contaminant analysis since 1979. Unfortunately, however, collections over the years have not been consistent with respect to sample size or location, rendering statistical comparisons coarse at best. That said, it appears that concentrations of PCBs, and the metals mercury, lead, cadmium and arsenic have trended downward (Table 14). Means were estimated by grouping samples over several time intervals, assuming a gamma distribution in a general linear model, and comparing results using the emmeans package. Bear in mind when interpreting the results in Table 14 that the highest overlap in rivers sampled was for the 1979-1997 and 2020-2021 time intervals.

Table 14 - Concentrations of contaminants measured in whole-body carp samples over three time intervals.

The number of parameter results reported by time interval varied for the 1979-1997 interval, but generally was about 110 results for the organic parameters and 50 for the metals. For the 1998-2018 interval, 37 results were reported for each organic parameter[16], and 18 results for metals. Twenty-five results per parameter were reported for 2020-2021.

	Time Interval	means	se	df	Lower C.I.	Upper C.I.
4,4-DDD	1979-1997	26.48	3.27	170	20.02	32.93
	1998-2018	18.96	4.06	170	10.95	26.97
	2020-2021	10.80	2.81	170	5.25	16.35
4,4-DDE	1979-1997	55.87	7.59	170	40.88	70.85
	1998-2018	42.23	9.94	170	22.61	61.85
	2020-2021	16.25	4.65	170	7.06	25.43
4,4-DDT	1979-1997	14.65	1.76	170	11.18	18.12
	1998-2018	7.75	1.61	170	4.57	10.92
	2020-2021	10.77	2.72	170	5.39	16.15
aldrin	1979-1997	7.03	0.68	169	5.69	8.37
	1998-2018	7.67	1.28	169	5.15	10.20
	2020-2021	10.76	2.18	169	6.45	15.07
arsenic	1979-1997	0.27	0.06	47	0.15	0.39
	1998-2018	0.11	0.02	47	0.08	0.14
	2020-2021	0.12	0.01	47	0.09	0.14
a-BHC	1979-1997	7.48	0.72	168	6.07	8.90
	1998-2018	7.68	1.27	168	5.18	10.17
	2020-2021	10.76	2.16	168	6.50	15.02
b-BHC	1979-1997	6.93	0.68	170	5.60	8.27
	1998-2018	7.68	1.30	170	5.12	10.24
	2020-2021	10.76	2.21	170	6.39	15.13
d-BHC	1979-1997	7.06	0.68	168	5.71	8.41
	1998-2018	7.68	1.28	168	5.16	10.19

[16] except mirex where 32 results were reported; selenium was another oddball

	Time Interval	means	se	df	Lower C.I.	Upper C.I.
	2020-2021	10.76	2.18	168	6.47	15.06
y-BHC	1979-1997	7.80	0.72	170	6.38	9.22
	1998-2018	7.68	1.23	170	5.26	10.10
	2020-2021	10.76	2.09	170	6.63	14.89
cadmium	1979-1997	0.09	0.02	92	0.06	0.12
	1998-2018	0.15	0.05	92	0.06	0.24
	2020-2021	0.05	0.01	92	0.02	0.07
endosulfan I	1979-1997	7.14	0.69	167	5.78	8.49
	1998-2018	7.68	1.26	167	5.18	10.17
	2020-2021	10.76	2.16	167	6.51	15.02
endosulfan ii	1979-1997	8.59	1.13	169	6.36	10.82
	1998-2018	7.68	1.74	169	4.23	11.12
	2020-2021	10.76	2.97	169	4.89	16.63
endosulfan sulfate	1979-1997	13.85	1.69	167	10.51	17.18
	1998-2018	7.68	1.60	167	4.51	10.84
	2020-2021	10.76	2.73	167	5.37	16.16
endrin	1979-1997	8.93	1.13	169	6.71	11.15
	1998-2018	7.68	1.67	169	4.38	10.97
	2020-2021	10.76	2.85	169	5.14	16.38
heptachlor	1979-1997	7.05	0.68	168	5.70	8.40
	1998-2018	7.68	1.28	168	5.15	10.20
	2020-2021	10.76	2.18	168	6.46	15.07
heptachlor epoxide	1979-1997	10.90	1.86	170	7.22	14.58
	1998-2018	7.68	2.27	170	3.19	12.16
	2020-2021	10.76	3.88	170	3.11	18.41
hexachlorobenzene	1979-1997	280.07	152.02	106	-21.32	581.45
	1998-2018	8.85	6.12	106	-3.29	20.99
	2020-2021	107.72	84.33	106	-59.46	274.91
lead	1979-1997	0.49	0.14	95	0.21	0.78
	1998-2018	0.82	0.41	95	0.00	1.64
	2020-2021	0.15	0.06	95	0.02	0.27
mercury	1979-1997	0.08	0.01	86	0.07	0.09
	1998-2018	0.09	0.01	86	0.07	0.12
	2020-2021	0.07	0.01	86	0.05	0.08
methoxychlor	1979-1997	72.99	9.25	165	54.73	91.26
	1998-2018	7.70	1.65	165	4.44	10.96
	2020-2021	10.76	2.81	165	5.22	16.31
mirex	1979-1997	20.09	2.78	148	14.60	25.59
	1998-2018	8.85	2.10	148	4.70	12.99
	2020-2021	10.76	2.89	148	5.06	16.47
PCB-1016	1979-1997	173.82	31.38	178	111.89	235.75
	1998-2018	35.85	11.61	178	12.94	58.75
	2020-2021	21.52	8.48	178	4.79	38.26
PCB-1221	1979-1997	175.48	31.36	178	113.60	237.37
	1998-2018	35.85	11.49	178	13.18	58.51
	2020-2021	21.52	8.39	178	4.96	38.08
PCB-1232	1979-1997	173.82	31.38	178	111.89	235.75
	1998-2018	35.85	11.61	178	12.94	58.75
	2020-2021	21.52	8.48	178	4.79	38.26
PCB-1242	1979-1997	275.82	67.45	180	142.73	408.91
	1998-2018	40.55	17.93	180	5.17	75.94
	2020-2021	24.58	13.22	180	-1.51	50.66

	Time Interval	means	se	df	Lower C.I.	Upper C.I.
PCB-1248	1979-1997	609.87	141.86	182	329.98	889.77
	1998-2018	208.16	88.28	182	33.98	382.34
	2020-2021	21.52	11.11	182	-0.39	43.44
PCB-1254	1979-1997	624.59	133.75	179	360.65	888.53
	1998-2018	175.19	67.56	179	41.87	308.51
	2020-2021	351.88	165.09	179	26.10	677.65
PCB-1260	1979-1997	840.80	114.26	185	615.38	1066.22
	1998-2018	249.25	62.50	185	125.93	372.56
	2020-2021	140.82	42.96	185	56.06	225.58
selenium	1979-1997	0.36	0.07	49	0.21	0.50
	1998-2018	0.41	0.06	49	0.29	0.54
	2020-2021	0.66	0.08	49	0.49	0.82

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Appendix A.

Sampling locations included in the Large River survey, 2020-2021.

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
Hocking River (01-001-000)						
J02W01	HOCKING R. AT LOGAN @ ST. RT. 93	68.33	510	WWH	39.5339	-82.4078
J02K06	HOCKING R. NEAR HAYDENVILLE @ WANDLING RD.	60.76	562	WWH	39.4739	-82.3294
J02K04	HOCKING R. AT NELSONVILLE @ NELSONVILLE CITY PARK	52.8	577	WWH	39.4506	-82.2297
J02P23	HOCKING R. N OF THE PLAINS @ ST. RT. 682	44	721	WWH	39.3886	-82.1408
J02S15	HOCKING R. AT ATHENS @ STIMSON AVE.	33.03	942	WWH	39.3308	-82.0875
J03P15	HOCKING R. NEAR GUYSVILLE @ U.S. RT. 50	20.6	982	WWH	39.2861	-81.9267
J03S10	HOCKING R. AT BEBEE @ TWP. RD. 189	13.56	1141	WWH	39.3117	-81.8575
Scioto River (02-001-000)						
V02W23	SCIOTO R. DST L. SCIOTO R, ADJ PROSPECT-UPPER SANDUSKY RD.	175.75	526	WWH	40.5006	-83.1979
V02P15	SCIOTO R. DST FULTON CREEK @ MINK STREET RD. (CO. RD. 177)	163.8	660	WWH	40.349996	-83.181802
201823	SCIOTO R. JUST S OF KLONDIKE, ADJ. KLONDIKE RD.	157.1	764	WWH	40.2672	-83.1469
V03P30	SCIOTO R. N OF DUBLIN @ I-270	145.57	990	WWH	40.1092	-83.1122
V03W25	SCIOTO R. AT COLUMBUS @ WEST 5TH AVE.	136.5	1049	WWH	39.9889	-83.0681
600860	SCIOTO R. AT COLUMBUS @ GREENLAWN AVE.	129.48	1617	WWH	39.9389	-83
600810	SCIOTO R. AT SHADEVILLE @ ST. RT. 665	119.9	1697	WWH	39.8325	-83.0083
600910	SCIOTO R. W OF SOUTH BLOOMFIELD @ ST. RT. 316	109.37	2311	EWH	39.7194	-83.0125
600960	SCIOTO R. AT CIRCLEVILLE @ U.S. RT. 22	99.82	3217	EWH	39.6014	-82.9553
201818	SCIOTO R. NEAR WESTFALL, UPST. B&E LANDFILL	94.2	3242	EWH	39.5547	-83.0008
600940	SCIOTO R. UPST. DEER CREEK @ KELLENBERGER RD.	86.4	3348	EWH	39.4728	-82.9961
201813	SCIOTO R. W OF U.S. RT.23/ST. RT. 159, DST. ISLAND	77.4	3828	EWH	39.3936	-82.9814
V13S09	SCIOTO R. 0.3 MI. DST. CHILLICOTHE WWTP	67.82	3853	EWH	39.3256	-82.9397
600770	SCIOTO R. DST. CHILLICOTHE @ HIGBY BRIDGE	56.17	5131	EWH	39.2122	-82.8647
201807	SCIOTO R. AT WAVERLY, 0.9 MI. UPST. ST. RT. 220	40	5750	WWH	39.1111	-82.9686
201805	SCIOTO R. AT PIKETON, 1.5 MI DST. U.S. RT. 23	33	5837	WWH	39.0797	-83.0283
V15P15	SCIOTO R. DST. PIKETON D.O.E., 2.3 MI. DST. SUNFISH CREEK	24.5	6086	WWH	38.9894667	-83.0386
V15K02	SCIOTO R. AT LUCASVILLE @ ST. RT. 348	14.67	6174	WWH	38.8811	-83.0178
V15W01	SCIOTO R. AT ROSEMOUNT, ADJ. U.S. RT. 23	5	6479	WWH	38.785	-82.9858
Big Darby Creek (02-200-000)						

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
V07S03	BIG DARBY CREEK W OF ORIENT @ ST. RT. 762	23.75	501	EWH	39.8022	-83.1692
601300	BIG DARBY CREEK AT DARBYVILLE @ ST. RT. 316	13.36	534	EWH	39.7008	-83.1097
600970	BIG DARBY CREEK NEAR FOX @ ST. RT. 104	3.2	552	EWH	39.6286	-83.0097
Olentangy River (02-400-000)						
V04S16	OLENTANGY R. AT COLUMBUS @ FOOTBRIDGE AT O.S.U.	2.7	537	MWH	40.000064	-83.023806
Paint Creek (02-500-000)						
300053	PAINT CREEK DST. PAINT CREEK DAM	39.14	570	EWH	39.2515	-83.3524
V10S28	PAINT CREEK N OF BAINBRIDGE @ ST. RT. 41	31.68	773	EWH	39.2349472	-83.2749
304031	PAINT CREEK CAMP TRAIL NEAR CALIFORNIA HOLLOW	23.5	827	EWH	39.2525375	-83.1789652
V10K17	PAINT CREEK 0.8 MI UPST N FK ADJ POLK HOLLOW RD @ BEND IN RD	8.9	895	EWH	39.305221	-83.035144
V10W12	PAINT CREEK BETWEEN U.S. RT. 23 AND ST. RT. 104	1.2	1143	WWH	39.3028	-82.9494
Salt Creek (02-600-000)						
V11G02	SALT CREEK @ MAIN CASE RD.	1.38	551	EWH	39.2	-82.8114
Grand River (03-001-000)						
G02G15	GRAND R. @ CORK COLD SPRING RD.	40.1	522	EWH	41.731	-80.8692
502510	GRAND R. UPST. MADISON @ ST. RT. 528	22.46	581	EWH	41.7406	-81.0467
G02W14	GRAND R. @ MADISON AVE./VROOMAN RD. BRIDGE	13.7	630	EWH	41.7258	-81.1844
G02S13	GRAND R. AT PAINESVILLE @ N. END OF PARK, ADJ. GOLF COURSE	6.1	687	EWH	41.7361	-81.2361
Maumee River (04-001-000)						
P06K10	MAUMEE R. 0.9 MI. DST. OHIO/INDIANA STATE LINE	107.1	2119	WWH	41.1686	-84.7944
201868	MAUMEE R. AT ANTWERP @ ANTWERP CITY PARK	99	2129	WWH	41.1839	-84.7325
P06S08	MAUMEE R. 4 MI. NE OF ANTWERP @ EATER RD	91.48	2134	WWH	41.2219	-84.6697
P06K06	MAUMEE R. N OF CECIL @ CO. RD. 105	85.26	2203	WWH	41.2378	-84.6022
P06S07	MAUMEE R. S OF THE BEND @ THE BEND RD.	76.15	2292	WWH	41.2753	-84.515
201858	MAUMEE R. E OF DEFIANCE, DST. INDEPENDENCE DAM	58.5	5548	WWH	41.2906	-84.2444
P09P02	MAUMEE R. 1.7 MI. DST. NAPOLEON WWTP, ADJ. ST. RT. 424	44.35	5681	MWH	41.4086	-84.0906
P11K33	MAUMEE R. AT GRAND RAPIDS @ ST. RT. 578 (BRIDGE ST.)	31.64	6058	WWH	41.4142	-83.8606
P11K31	MAUMEE R. NEAR OTSEGO @ CONFLUENCE OF SUGAR CREEK	26.7	6264	WWH	41.4481	-83.7858
500080	MAUMEE R. AT WATERVILLE @ ST. RT. 64	20.68	6330	WWH	41.5	-83.7128
301740	MAUMEE R. @ BUTTONWOOD RECREATION AREA	16.52	6340	WWH	41.548042	-83.674944

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
Auglaize River (04-100-000)						
500110	AUGLAIZE R. AT CLOVERDALE @ ST. RT. 114	28.5	719	WWH	41.020821	-84.288697
P06S10	AUGLAIZE R. AT CHARLOE @ CO. RD. 138	14.94	2041	MWH	41.1286	-84.4319
500290	AUGLAIZE R. UPST. DEFIANCE @ HARDING RD.	4.14	2330	WWH	41.2538	-84.3896
Blanchard River (04-160-000)						
P05S03	BLANCHARD R. AT GILBOA @ CO. RD. 5-F	35.24	508	WWH	41.0162	-83.9221
500100	BLANCHARD R. UPST. OTTAWA @ CO. RD. 8	28.88	624	WWH	41.0124	-84.0153
P05S01	BLANCHARD R. @ PUTNAM CO. RD. 15	13.37	704	WWH	41.0575	-84.1502
St. Joeseph River (04-400-000)						
510220	ST. JOSEPH R. NEAR OHIO/INDIANA STATE LINE @ ST. RT. 249	42.34	609	WWH	41.3856	-84.8017
Tiffin River (04-600-000)						
P07K01	TIFFIN R. S OF EVANSPORT @ STEVER RD.	14	562	WWH	41.388864	-84.399755
500160	TIFFIN R. NEAR DEFIANCE @ DEY RD.	0.89	775	MWH	41.2903	-84.3856
Sandusky River (05-001-000)						
U03G01	SANDUSKY R. S OF MCCUTCHENVILLE @ CO. RD. 16	65.01	656	WWH	40.964819	-83.268588
U04S29	SANDUSKY R. NEAR MEXICO @ CO. RD. 9	57.34	760.1	WWH	40.988818	-83.203749
U04S28	SANDUSKY R. AT TIFFIN @ ELLA ST.	41.84	964.2	WWH	41.103955	-83.186619
500910	SANDUSKY R. DST TIFFIN @ ABBOTTS BRIDGE	30.85	1048.2	WWH	41.20969	-83.145172
U04Q06	SANDUSKY R. UPST. FREMONT, UPST. WOLF CREEK	23	1072	WWH	41.2779583	-83.1647306
U04S23	SANDUSKY R. AT FREMONT @ TIFFIN RD.	17.7	1255.3	WWH	41.327097	-83.130412
Raccoon Creek (09-500-000)						
W03S44	RACCOON CREEK AT WOODS MILL @ EAGLE RD.	35.61	542	EWH	38.9378	-82.3392
601400	RACCOON CREEK AT ADAMSVILLE @ U.S. RT. 35	29.2	586	EWH	38.8736	-82.3561
303503	RACCOON CREEK ADJ. DAN JONES RD	22	615	EWH	38.8038016	-82.3708
W03S24	RACCOON CREEK AT NORTHUP, DST. DAM	10.2	648	EWH	38.7839	-82.2819
Little Miami River (11-001-000)						
M05K01	L. MIAMI R. DST CAESAR CREEK @ SHAW PROPERTY	50.25	658	EWH	39.4866	-84.1104
M05S12	L. MIAMI R. NEAR FORT ANCIENT @ ST. RT. 350	43.76	680	EWH	39.4069083	-84.1010111
610520	L. MIAMI R. NEAR MORROW @ STUBBS MILL RD.	35.98	964	EWH	39.363425	-84.1736694
M05W34	L. MIAMI R. AT LOVELAND, 0.1 MI UPST. O'BANNON CREEK	24.1	1085	EWH	39.2713	-84.2596
M05P11	L. MIAMI R. AT MILFORD @ WOOSTER PIKE	13.07	1203	EWH	39.1717	-84.2986
600580	L. MIAMI R. @ BEECHMONT AVE. (ST. RT 125/32)	3.5	1744	EWH	39.109	-84.4015

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
Great Miami River (14-001-000)						
201922	GREAT MIAMI R. JUST DST. SWIFT RUN LAKE OUTLET STREAM	118.5	842	EWH	40.1736	-84.2572
H05S05	GREAT MIAMI R. AT TROY @ ST. RT. 41	106.1	927	EWH	40.0306	-84.1875
H05S19	GREAT MIAMI R. E OF TIPP CITY @ ST. RT. 571	98.97	1124	EWH	39.9583	-84.1403
H05W01	GREAT MIAMI R. NEAR MIAMI VILLA @ LITTLE YORK RD.	91.14	1154	EWH	39.8544	-84.1718
H05K01	GREAT MIAMI R. AT DAYTON @ I-75 BETWEEN STILLWATER R./MAD R.	81.8	1853	WWH	39.7731	-84.1914
H09W02	GREAT MIAMI R. AT DAYTON @ STEWART ST.	78.85	2587	WWH	39.74	-84.1933
H09S13	GREAT MIAMI R. AT MIAMISBURG @ LINDEN AVE.	66.9	2711	WWH	39.6406	-84.2922
H09W28	GREAT MIAMI R. N OF MIDDLETOWN @ ST. RT. 4	55.14	3117	WWH	39.5399	-84.3841
H09W28	GREAT MIAMI R. N OF MIDDLETOWN @ ST. RT. 4	55.14	3117	WWH	39.5399	-84.3841
H09W78	GREAT MIAMI R. DST. AK STEEL 011, BETWEEN CSOS	51.24	3137	WWH	39.5015	-84.4192
600330	GREAT MIAMI R. NEAR MIDDLETOWN @ ST. RT. 73	49.27	3189	WWH	39.481576	-84.442037
600330	GREAT MIAMI R. NEAR MIDDLETOWN @ ST. RT. 73	49.27	3189	WWH	39.481576	-84.442037
201886	GREAT MIAMI R. UPST. 0.4 MI. UPST. LIBERTY-FAIRFIELD RD.	43.6	3278	WWH	39.4319	-84.4706
610090	GREAT MIAMI R. @ LIBERTY-FAIRFIELD RD.	43.23	3280	WWH	39.4293	-84.4764
610090	GREAT MIAMI R. @ LIBERTY-FAIRFIELD RD.	43.23	3280	WWH	39.4293	-84.4764
H11W35	GREAT MIAMI R. 0.1 MI. UPST. HAMILTON WWTP	34.1	3636	WWH	39.3718	-84.5702
H11W35	GREAT MIAMI R. 0.1 MI. UPST. HAMILTON WWTP	34.1	3636	WWH	39.3718	-84.5702
H11C01	GREAT MIAMI R. DST FERNALD, 1.0 MI DST. DRY RUN	24.55	3799	WWH	39.2925	-84.6647
H11W20	GREAT MIAMI R. AT MIAMITOWN @ HARRISON RD.	15.49	3838	WWH	39.2161	-84.7035
H11W20	GREAT MIAMI R. AT MIAMITOWN @ HARRISON RD.	15.49	3838	WWH	39.2161	-84.7035
H11K14	GREAT MIAMI R. AT HOOVEN, UPST. U.S. RT. 50, UPST. REFINERY	9.5	3872	WWH	39.1797	-84.7481
Mad River (14-100-000)						
H04P09	MAD R. NEAR ENON @ SNIDER RD.	17.48	527	WWH	39.885534	-83.966623
H04S03	MAD R. DST. FAIRBORN WWTP	8.7	616	WWH	39.8264	-84.0633
H04P23	MAD R. AT DAYTON @ WEBSTER ST.	0.28	657	WWH	39.7683	-84.1836
Stillwater River (14-200-000)						
H06P03	STILLWATER R. NEAR PLEASANT HILL @ LAUVER RD.	27.86	503	EWH	40.0578	-84.3558
H06P07	STILLWATER R. S OF PLEASANT HILL @ FENNER RD.	23.44	523	EWH	40.0228	-84.3406

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
H06P09	STILLWATER R. AT WEST MILTON @ ST. RT. 571	17.45	602	EWH	39.9644	-84.3242
H06S11	STILLWATER R. NEAR UNION @ MARTINDALE RD.	11.39	645	EWH	39.8986	-84.2933
H06W30	STILLWATER R. AT IRVINGTON @ DOG LEG RD.	5.78	660	EWH	39.8383	-84.2458
H06K01	STILLWATER R. AT DAYTON @ SIEBENTHALER RD.	1.5	674	EWH	39.8	-84.2058
Whitewater River (14-300-000)						
H11W65	WHITEWATER R. @ LANE OFF LAWRENCEBURG RD, 1.8 MI. N OF I-275	3.8	1384	EWH	39.2094	-84.7931
Muskingum River (17-001-000)						
300146	MUSKINGUM R. DST. WALHONDING R./TUSCARAWAS R.	110.7	4852	WWH	40.2688333	-81.8757222
611740	MUSKINGUM R. DST. COSHOCTON @ ST. RT. 83	108.28	4861	WWH	40.2361	-81.8717
611740	MUSKINGUM R. DST. COSHOCTON @ ST. RT. 83	108.28	4861	WWH	40.2361	-81.8717
R11W03	MUSKINGUM R. 1.5 MILES UPST. WILLS CREEK	101.8	4883	WWH	40.1664	-81.8875
611750	MUSKINGUM R. AT DRESDEN @ ST. RT. 208	92	5993	WWH	40.1206	-82
R11S12	MUSKINGUM R. JUST DST. ELLIS DAM	84.7	6042	WWH	40.0411	-81.9861
R16P06	MUSKINGUM R. AT ZANESVILLE @ U.S. RT. 22/6TH ST.	75.67	6850	WWH	39.935	-82.0061
R16P08	MUSKINGUM R. @ DUNCAN FALLS BRIDGE	67.48	7196	WWH	39.8692	-81.9094
R16S28	MUSKINGUM R. JUST DST ROKEBY LOCK DAM	56.4	7386	WWH	39.731	-81.9061
R16S39	MUSKINGUM R. AT MCCONNELSVILLE @ LOCK CHANNEL	48.81	7422	WWH	39.6439	-81.8472
R16S06	MUSKINGUM R. DST. STOCKPORT DAM	39.3	7457	WWH	39.5431	-81.7906
R16S20	MUSKINGUM R. DST. LUKE CHUTE DAM	33.5	7470	WWH	39.5394	-81.7236
R19K07	MUSKINGUM R. DST. BEVERLY DAM, UPST. WOLF CREEK	24.8	7713	WWH	39.5533	-81.6478
R19K05	MUSKINGUM R. AT LOWELL, DST. LOWELL DAM	14	7995	WWH	39.5286	-81.5147
R19K02	MUSKINGUM R. DST. DEVOLA DAM	5.7	8035	WWH	39.4689	-81.4897
Killbuck Creek (17-150-000)						
R04S02	KILLBUCK CREEK AT LAYLAND @ ST. RT. 60	18.36	503	WWH	40.4358	-81.9661
203603	KILLBUCK CREEK AT HELMICK @ COVERED BRIDGE (TWP. RD. 25)	13.28	581	WWH	40.3928	-81.9433
203602	KILLBUCK CREEK 1.5 MI UPST. CO. RD. 28, ADJ CO. RD. 24	2.1	599	WWH	40.345	-81.9489
Licking River (17-200-000)						
601770	LICKING R. NEAR NEWARK @ ST. RT. 16 (STADDEN BRIDGE)	26.75	537	WWH	40.059357	-82.338683
601770	LICKING R. NEAR NEWARK @ ST. RT. 16 (STADDEN BRIDGE)	26.75	537	WWH	40.059357	-82.338683

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
603300	LICKING R. AT TOBOSO @ TOBOSO RD.	18.87	672	WWH	40.0567	-82.2203
R13S27	LICKING R. AT DILLON FALLS @ DILLON FALLS RD.	3.68	753	WWH	39.9707	-82.0565
Sandy Creek (17-450-000)						
R07S71	SANDY CREEK E OF BOLIVAR, JUST DST. BOLIVAR DAM	0.57	504	WWH	40.6511	-81.4342
Tuscarawas River (17-500-000)						
R06W79	TUSCARAWAS R. 0.13 MI. UPST. MASSILLON WWTP	89	518	WWH	40.7706	-81.5242
R06A02	TUSCARAWAS R. W OF BOLIVAR @ ST. RT. 212 (DOLPHIN ST.)	78.16	574	WWH	40.6547	-81.4856
R06P75	TUSCARAWAS R. NEAR BOLIVAR @ SHERMAN CHURCH AVE.	73.67	586	WWH	40.6633	-81.4394
R10K18	TUSCARAWAS R. NE OF DOVER @ POWER LINES DST. DOVER DAM	63.2	1404	WWH	40.5519	-81.4208
R10K12	TUSCARAWAS R. NEAR NEW PHILADELPHIA, 1.0 MI DST U.S. RT. 250	52.3	1816	WWH	40.4642	-81.4308
R10K10	TUSCARAWAS R. AT TUSCARAWAS @ CO. RD. 62	44.5	2364	EWH	40.3944	-81.3903
R10G02	TUSCARAWAS R. UPST. GNADENHUTTEN WWTP	38.68	2381	EWH	40.359	-81.442
611790	TUSCARAWAS R. AT NEWCOMERSTOWN @ RIVER ST.	21.17	2443	EWH	40.2611	-81.6097
R10S11	TUSCARAWAS R. NEAR ORANGE @ ST. RT. 751	15.25	2480	EWH	40.2856	-81.6844
601840	TUSCARAWAS R. AT WEST LAFAYETTE @ ST. RT. 93	10.73	2566	EWH	40.2919	-81.75
611730	TUSCARAWAS R. AT COSHOCTON @ KIA BRIDGE	0.3	2596	EWH	40.2789	-81.8706
Walhonding River (17-600-000)						
601910	WALHONDING R. AT NELLIE @ US RT 36	15.73	1505	EWH	40.3414	-82.0647
300288	WALHONDING R. UPST. SIXMILE DAM	8.81	1572	EWH	40.3277	-81.9655
R04S35	WALHONDING R. UPST. KILLBUCK CREEK @ US RT 36	7.54	1575	EWH	40.327364	-81.9428
R04W27	WALHONDING R. AT COSHOCTON @ US RT 36	0.76	2255	EWH	40.2839	-81.8706
Mohican River (17-700-000)						
300286	MOHICAN R. ADJ. WALLY RD. (ASHLAND CR 3175)	27	573	EWH	40.6029	-82.2481
601870	MOHICAN R. AT GREER @ SR 514	16.92	948	EWH	40.522597	-82.196184
304208	MOHICAN R. AT BRINKHAVEN UPST. LOWHEAD DAM	11.8	966	EWH	40.469299	-82.197308
200636	MOHICAN R. AT BRINKHAVEN, UPST. US RT 62	11.5	967	EWH	40.46598	-82.19437
300284	MOHICAN R. AT TIVERTON @ TWP. RD. 365	6.53	987.7	EWH	40.4127	-82.1786
200634	MOHICAN R. NEAR MOUTH @ SR 715	0.45	998	EWH	40.365721	-82.157175
Wills Creek (17-800-000)						

STATION ID	Station Name	River Mile	Drainage Area	Aquatic Life Use	Latitude	Longitude
R18S01	WILLS CREEK DST. SALT FORK @ TWP. RD. 365	46.57	659	WWH	40.1217	-81.5928
R18S22	WILLS CREEK SE OF BIRDS RUN @ ST. RT. 541	37.74	672	WWH	40.1614	-81.6256
302624	WILLS CREEK S OF PLAINFIELD, DST. BACON RUN @ ST. RT. 93	18.54	770.5	WWH	40.204599	-81.714224
611770	WILLS CREEK DST. WILLS CREEK DAM @ TWP. RD. 274 (USGS GAGE)	7.04	842	WWH	40.1594	-81.8475
Mahoning River (18-001-000)						
N03K31	MAHONING R. AT LTV WARREN, NEAR SUBSTATION	36.2	606	WWH	41.2136	-80.8156
N03S56	MAHONING R. AT GIRARD, DST. LIBERTY ST. DAM	26.36	880	WWH	41.1544	-80.7061
N03W21	MAHONING R. AT CAMPBELL, NEAR RR	17.63	1017	WWH	41.0761	-80.6161
602300	MAHONING R. AT LOWELLVILLE @ FIRST ST.	12.42	1074	WWH	41.0361	-80.5361
N03S51	MAHONING R. @ OHIO/PA STATE LINE	11.43	1075	WWH	41.03	-80.5192
Cuyahoga River (19-001-000)						
F01S13	CUYAHOGA R. AT JAITE @ HIGHLAND RD.	24.1	555	WWH	41.288764	-81.56504
F01S11	CUYAHOGA R. @ HILLSIDE RD.	15.61	698	WWH	41.373264	-81.614786
F01S09	CUYAHOGA R. DST. NEORSD SOUTHERLY WWTP @ CONRAIL RR	9.7	744	WWH	41.4269	-81.6658

Supplemental Information

R code for obtaining USGS flow data and evaluating temperature and TKN trends.

```
##read dbf created from GIS##
library(foreign)
usgs<-read.dbf("Ambientusg.dbf",as.is=TRUE)

summary(usgs)
dim(usgs)
usgs[1,]


#get the gauge IDs#
usgsid<-na.omit(as.data.frame(unique(usgs$STAID)))

dim(usgsid)


#get gauge data#
library(dataRetrieval)


usgsid[1,1]

#pull the data for the first station#

siteNo <-usgsid[1,1]
pCode <- "00060"
start.date <- "1981-03-01"
end.date <- "2021-10-30"

ffs <- readNWISuv(siteNumbers = siteNo,
                  parameterCd = pCode,
                  startDate = start.date,
                  endDate = end.date)

#loop for subsequent stations; this took a fair bit of time#

i=2

while(i<41){
siteNo <-usgsid[i,1]
pCode <- "00060"
start.date <- "1981-03-01"
end.date <- "2021-10-30"
```

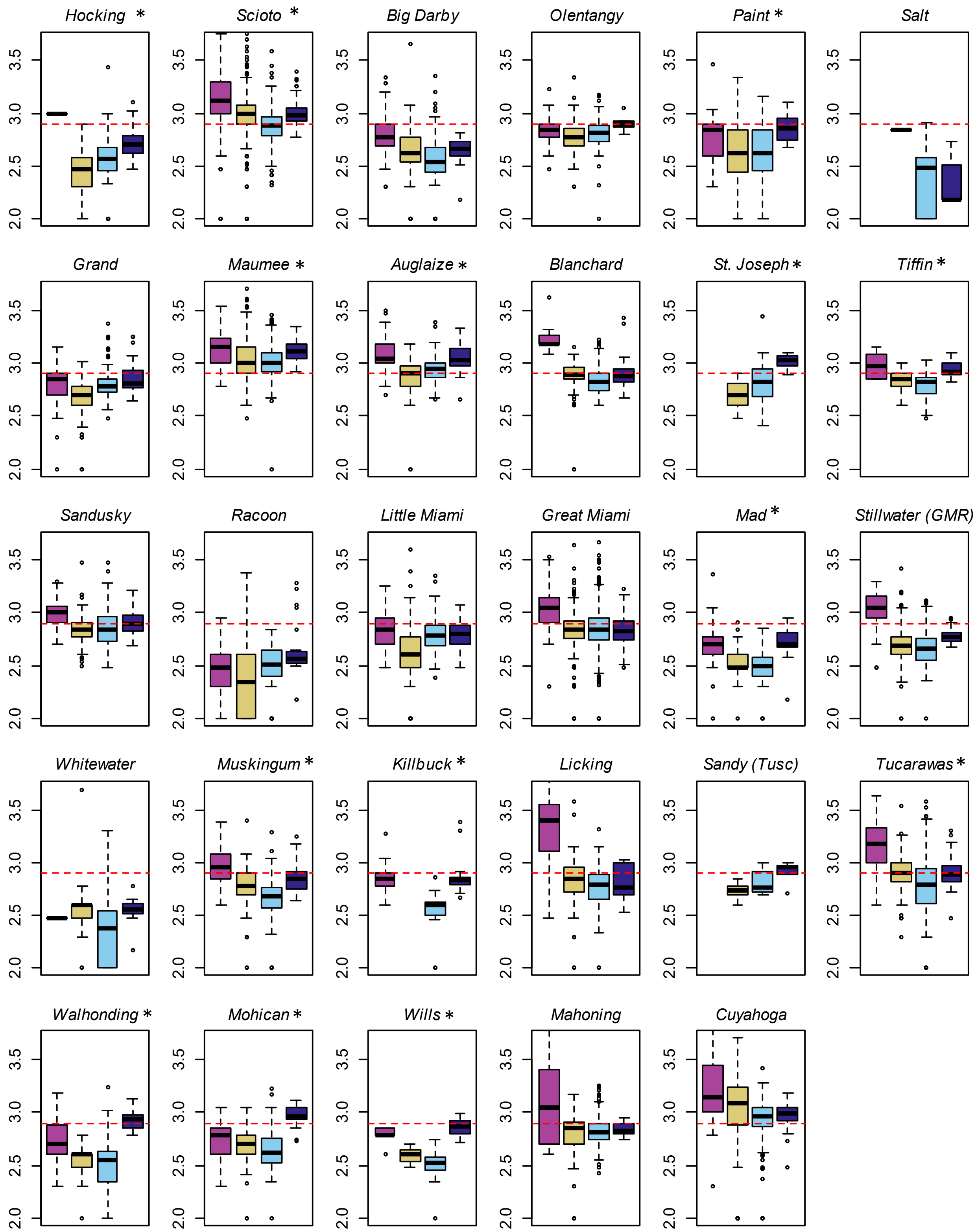
```
ffs2 <- readNWISuv(siteNumbers = siteNo,
                   parameterCd = pCode,
                   startDate = start.date,
                   endDate = end.date)

ffs<-rbind(ffs,ffs2)
i=i+1
}


dim(ffs)
summary(ffs)

#load chemistry data#
ambx<-readRDS("ambx.rds")

#make dates a common format; lubridate isn't necessary, but I loaded it#
library(lubridate)

ambx$xdate<-paste(substr(ambx$CDATE,1,2),"-",substr(ambx$CDATE,4,5),"-
",substr(ambx$CDATE,7,10),sep="")
ffs$CDATE<-as.character(ffs$dateTime)
ffs$xdate<-paste(substr(ffs$CDATE,6,7),"-",substr(ffs$CDATE,9,10),"-",substr(ffs$CDATE,1,4),sep="")


dim(ffs)
summary(usgs)
dim(ambx)
summary(ambx)
grep("YR",colnames(ambx))
grep("CDATE",colnames(ambx))
grep("STORET",colnames(ambx))
grep("xdate",colnames(ambx))
grep("",colnames(ambx))

#look at date format; mix of hyphens and slashes as separators in old chem#
ambx[7000,45]


summary(ffs)
ambx$xdate<-paste(substr(ambx$CDATE,1,2),"-",substr(ambx$CDATE,4,5),"-
",substr(ambx$CDATE,7,10),sep="")
ambx[1,47]
```

```
ffs$xdate<-paste(substr(ffs$CDATE,6,7),"-",substr(ffs$CDATE,9,10),"-",substr(ffs$CDATE,1,4),sep="")
dim(ffs)

ffs[1,8]



grep("STORET",colnames(usgs))
grep("STAID",colnames(usgs))
grep("",colnames(usgs))


summary(ambx)



#merge in STORET id#

ffs<-merge(ffs,usgs[c(8,4)],by.x="site_no",by.y="STAID")
summary(ffs)
names(ffs)[4]<-"flow"


#median flow for the day#
xflow<-aggregate(ffs$flow,by=list(ffs$STORET,ffs$xdate),median)
summary(xflow)
xflow[1,]
names(xflow)[1:3]<-c("STORET","xdate","mflow")

#merge flow and chemistry data; I like to make sure the row dimensions match#
ambz<-merge(ambx,xflow,by=c("STORET","xdate"))
dim(ambz)
dim(ambx)
summary(ambz)

#log tranform flow#
ambz$flows<-log10(ambz$mflow)
summary(ambz)

length(unique(ambz$STORET))

#prepping for stats#
ambtkn<-subset(ambz,YR>2002,!is.na(tkn))
dim(ambtkn)
table(ambtkn$STORET)
```

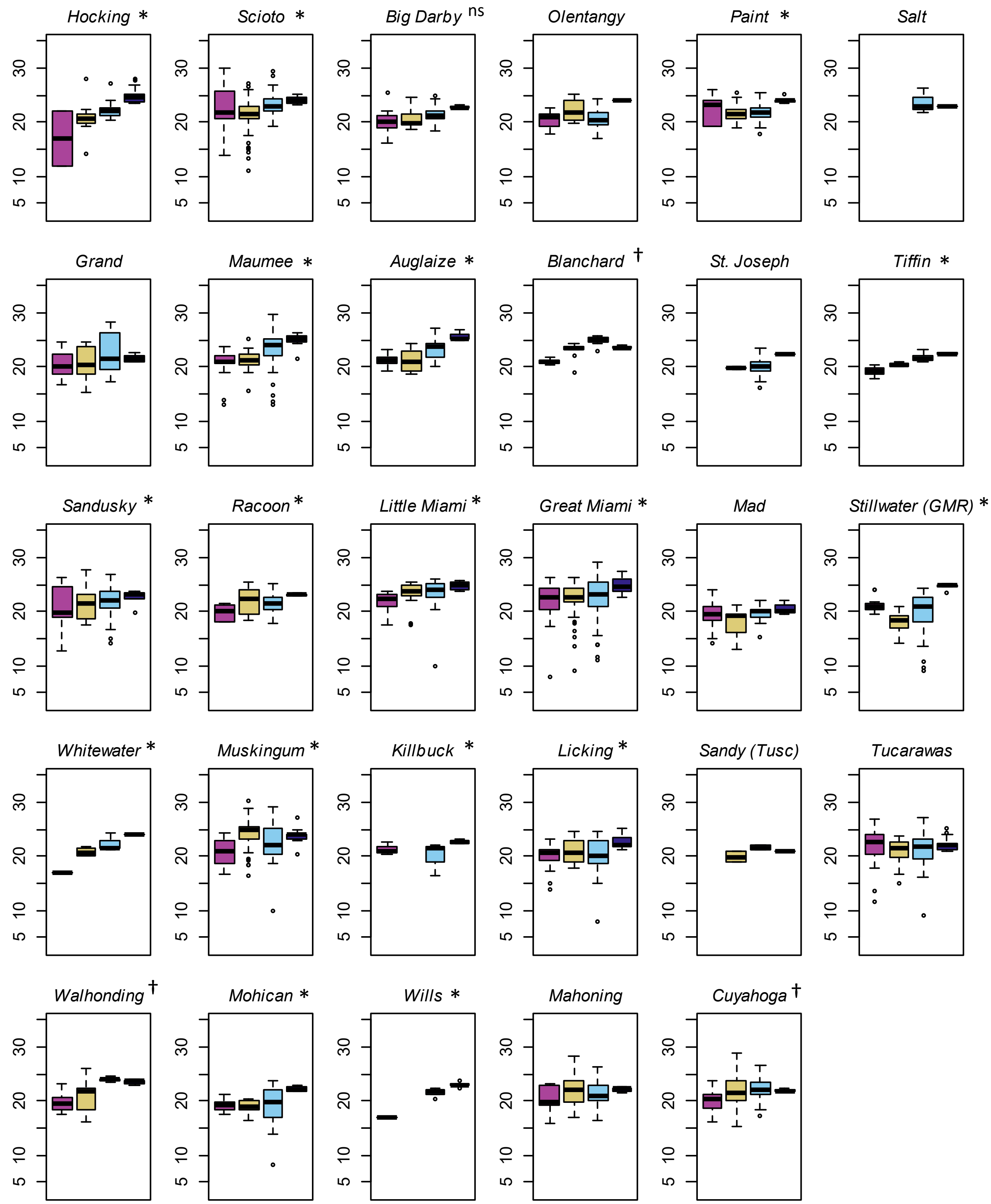
```
grep("STORET",colnames(ambtkn))
grep("YR",colnames(ambtkn))
grep("flows",colnames(ambtkn))
grep("tkn",colnames(ambtkn))
grep("TempC",colnames(ambtkn))


library(lme4)

tknfit1<-lmer(tkn~flows+TempC+YR+(1|STORET),subset(ambtkn,!is.na(TempC)))

tknfit2<-lmer(tkn~YR+flows:STORET+(1|STORET),subset(ambtkn,!is.na(TempC)))

tknfit3<-lmer(tkn~YR+TempC+flows:STORET+(1|STORET),subset(ambtkn,!is.na(TempC)))

tknfit4<-lmer(tkn~TempC+flows:STORET+(1|STORET),subset(ambtkn,!is.na(TempC)))


anova(tknfit4,tknfit3,tknfit2,tknfit1)


predtkn<-predict(tknfit3,newdata=ambtkn[c(1,40,41,47,49)])

summary(ambtkn)

ambtkn$predtkn<-predtkn


#the plots you see above#
par(mfrow=c(2,2))
par(mar=c(4,4,2,1))
boxplot(tkn~YR,subset(ambz,YR>2002),ylab="Log10 TKN ug/L",xlab="Year")
plot(tkn~flows,subset(ambz,YR>2002),pch=21,bg="azure",ylab="Log10 TKN ug/L",xlab="Log10 Flow CFS")


boxplot(predtkn~YR,ambtkn,ylab="Predicted TKN",xlab="Year")
plot(predtkn~flows,ambtkn,ylab="Predicted TKN", xlab="Log10 Flow CFS",pch=21,bg="aliceblue")


# summary for tknfit3#
Linear mixed model fit by REML ['lmerMod']
Formula: tkn ~ YR + TempC + flows:STORET + (1 | STORET)
   Data: subset(ambtkn, !is.na(TempC))

REML criterion at convergence: -468.5
```

```
Scaled residuals:
    Min      1Q  Median      3Q     Max
-5.2063 -0.4475  0.0743  0.5338  5.7660

Random effects:
 Groups   Name        Variance Std.Dev.
 STORET   (Intercept) 0.06186  0.2487
 Residual             0.03802  0.1950
Number of obs: 1484, groups:  STORET, 17

Fixed effects:
                         Estimate   Std. Error   t value
(Intercept)            -5.7213374    2.0936415    -2.733
YR                      0.0041208    0.0010405     3.961
TempC                   0.0026595    0.0006874     3.869
flows:STORET 500080     0.0436796    0.0255850     1.707
flows:STORET 500820     0.1269910    0.0303876     4.179
flows:STORET 502020     0.0161220    0.0558461     0.289
flows:STORET 502530     0.0835117    0.0392190     2.129
flows:STORET 510220     0.1705640    0.0321081     5.312
flows:STORET 600770    -0.0096346    0.0360757    -0.267
flows:STORET 601290     0.0886452    0.0379800     2.334
flows:STORET 601300     0.1447957    0.0328663     4.406
flows:STORET 601770    -0.0146715    0.0408614    -0.359
flows:STORET 602000     0.0677618    0.0529993     1.279
flows:STORET 602280     0.1137295    0.0546138     2.082
flows:STORET 602300     0.0509325    0.0599346     0.850
flows:STORET H06P03     0.1772137    0.0360110     4.921
flows:STORET J02S15    -0.0612456    0.0350459    -1.748
flows:STORET P09W19     0.0326456    0.0286808     1.138
flows:STORET S02P08     0.0269626    0.0336304     0.802
flows:STORET V10P06     0.1449953    0.0285815     5.073

Correlation matrix not shown by default, as p = 20 > 12.
Use print(x, correlation=TRUE)  or
    vcov(x)        if you need it

Linear mixed model fit by REML ['lmerMod']
Formula: OrgN ~ YR + TempC + flows:STORET + (1 | STORET)
   Data: subset(ambon, !is.na(TempC))

REML criterion at convergence: -108.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
```

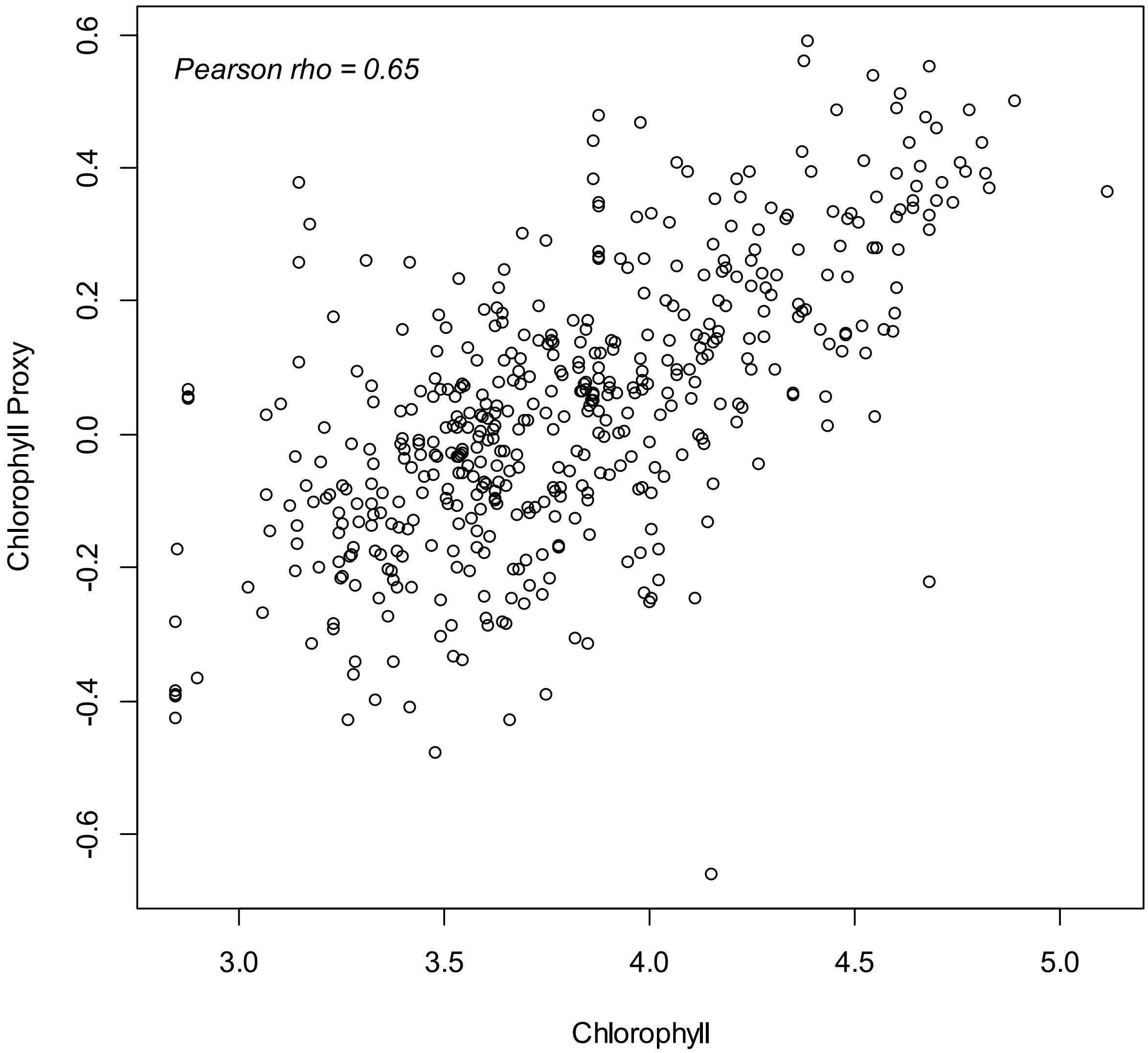
```
-7.0898 -0.3969  0.0902  0.5169  5.9446

Random effects:
 Groups   Name        Variance Std.Dev.
 STORET   (Intercept) 0.06655  0.2580
 Residual             0.04868  0.2206
Number of obs: 1483, groups:  STORET, 17

Fixed effects:
                     Estimate Std. Error t value
(Intercept)        -7.1268040  2.3688655  -3.009
YR                  0.0048024  0.0011773   4.079
TempC               0.0031425  0.0007784   4.037
flows:STORET500080  0.0285055  0.0286727   0.994
flows:STORET500820  0.1102658  0.0340925   3.234
flows:STORET502020 -0.0065663  0.0610711  -0.108
flows:STORET502530  0.0738662  0.0437385   1.689
flows:STORET510220  0.1658530  0.0360221   4.604
flows:STORET600770 -0.0191871  0.0399175  -0.481
flows:STORET601290  0.0715553  0.0425072   1.683
flows:STORET601300  0.1461219  0.0368849   3.962
flows:STORET601770  0.0153989  0.0455968   0.338
flows:STORET602000  0.0600203  0.0584479   1.027
flows:STORET602280  0.1127431  0.0599382   1.881
flows:STORET602300  0.0496090  0.0650277   0.763
flows:STORETH06P03  0.1573490  0.0403929   3.895
flows:STORETJ02S15 -0.1201946  0.0391761  -3.068
flows:STORETP09W19  0.0368429  0.0320613   1.149
flows:STORETS02P08  0.0258816  0.0378777   0.683
flows:STORETV10P06  0.1295989  0.0320790   4.040
```



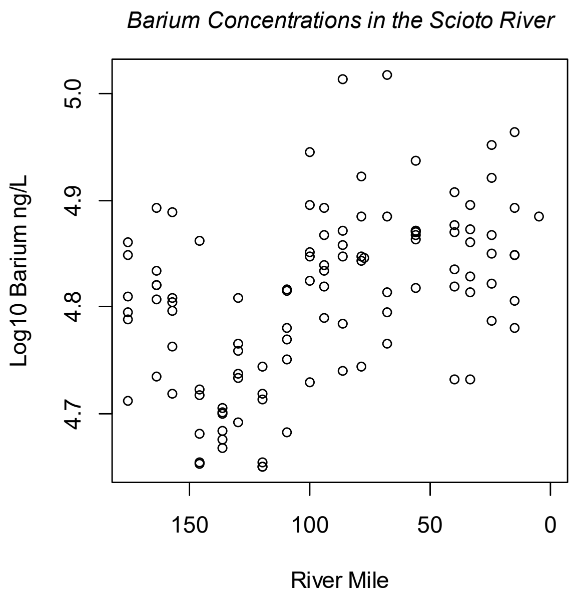
TKN trends for the ambient stations, log10 ug/L.

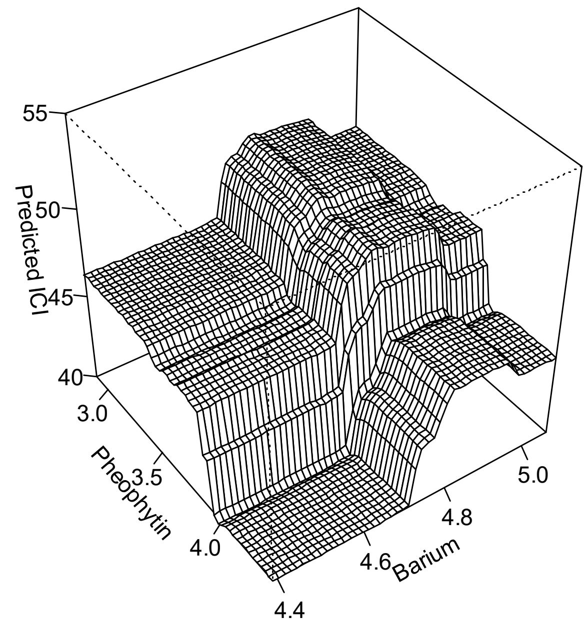


Temperature trends by river, ˚C.



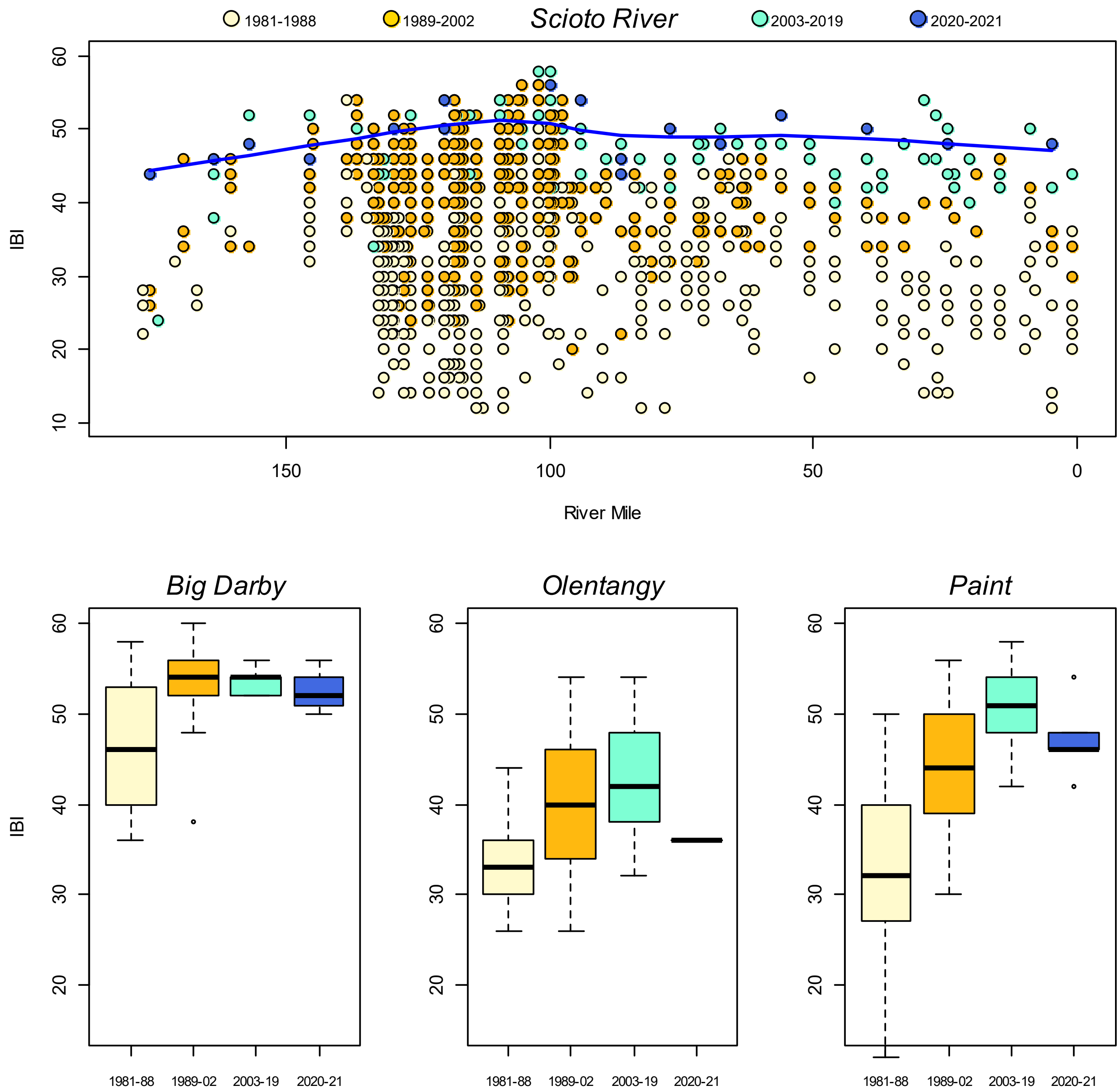
Residuals from a regression of iron on total suspended solids plotted against sestonic chlorophyll concentrations (log 10 ng/l)

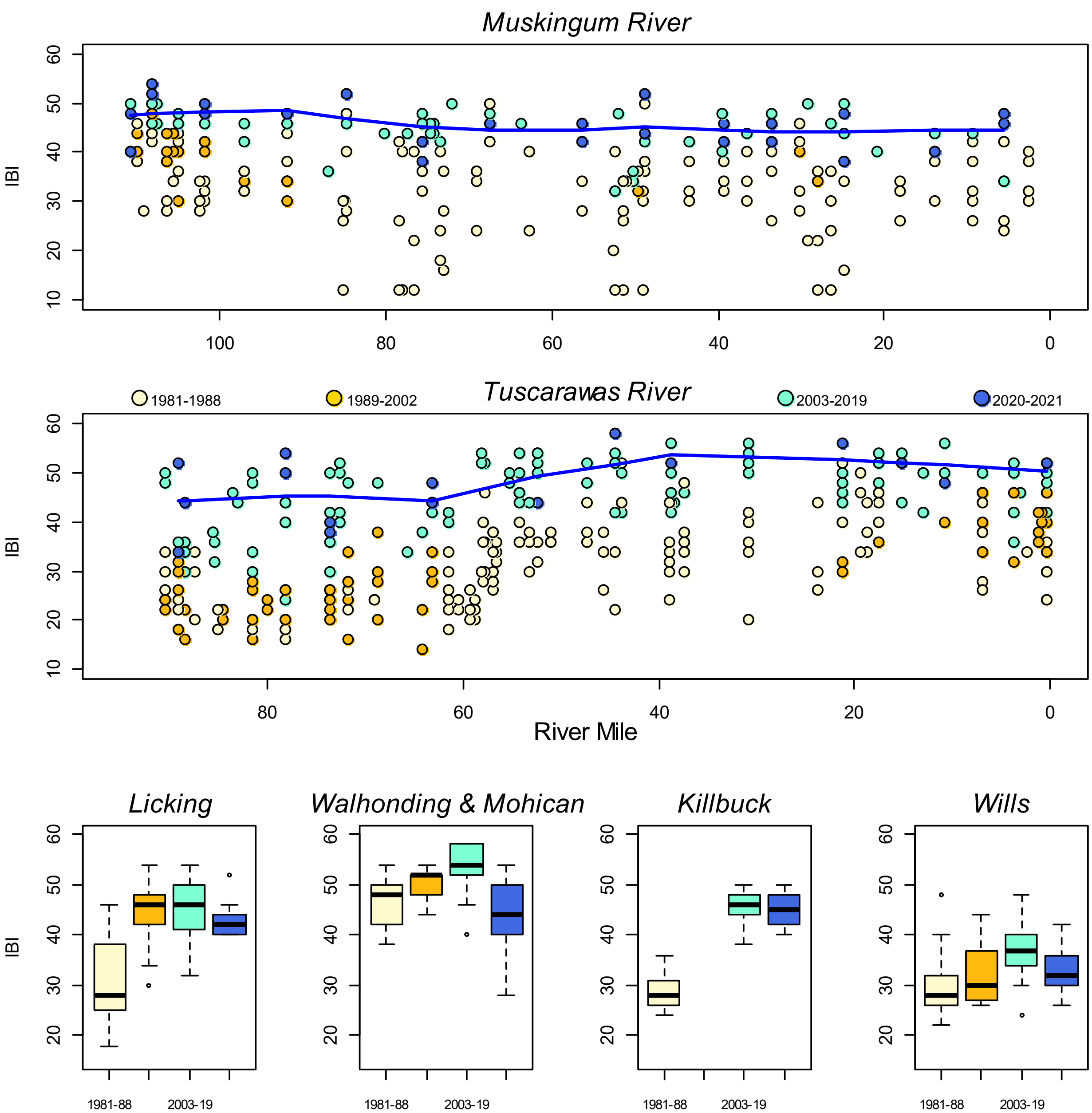


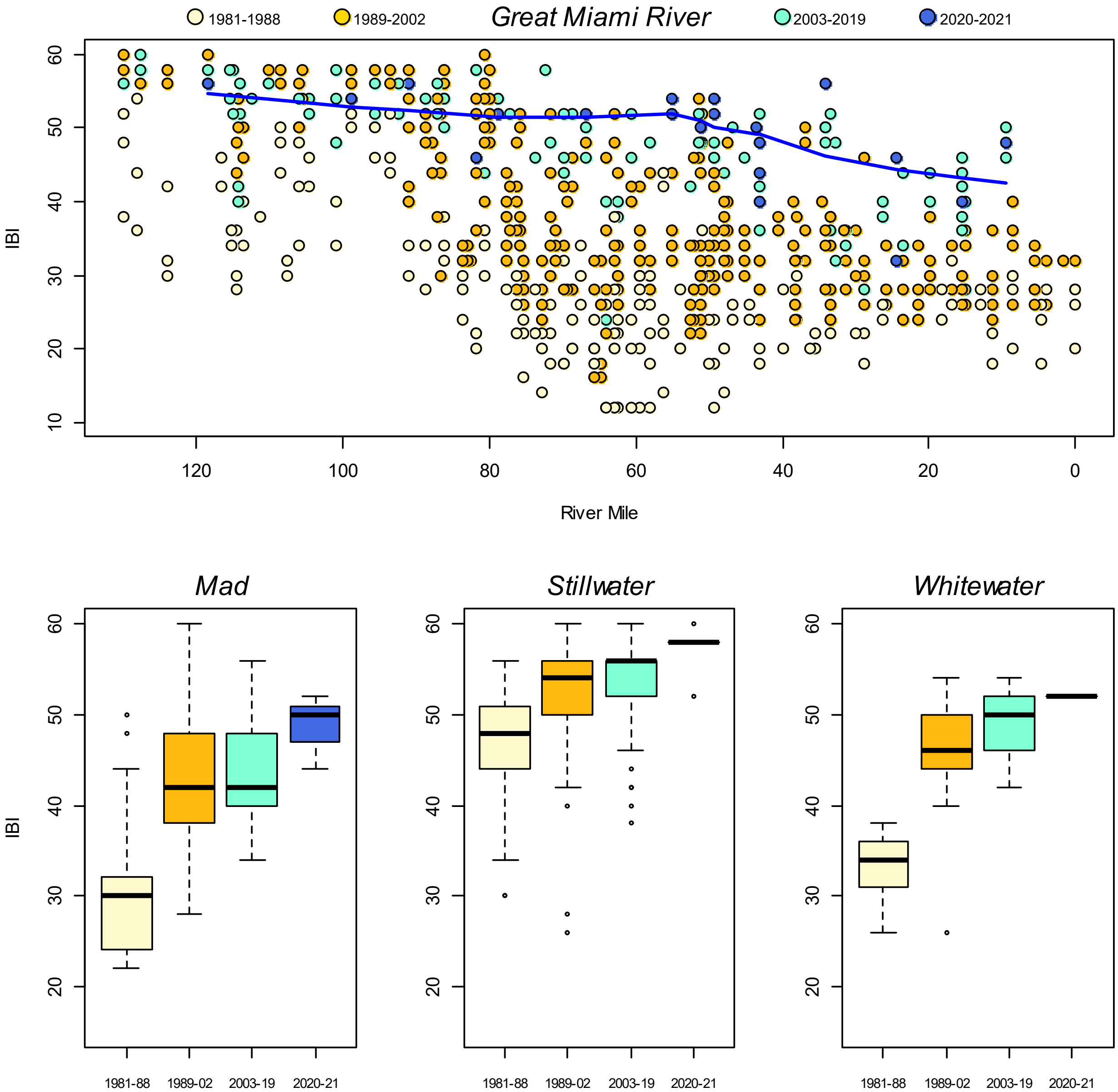


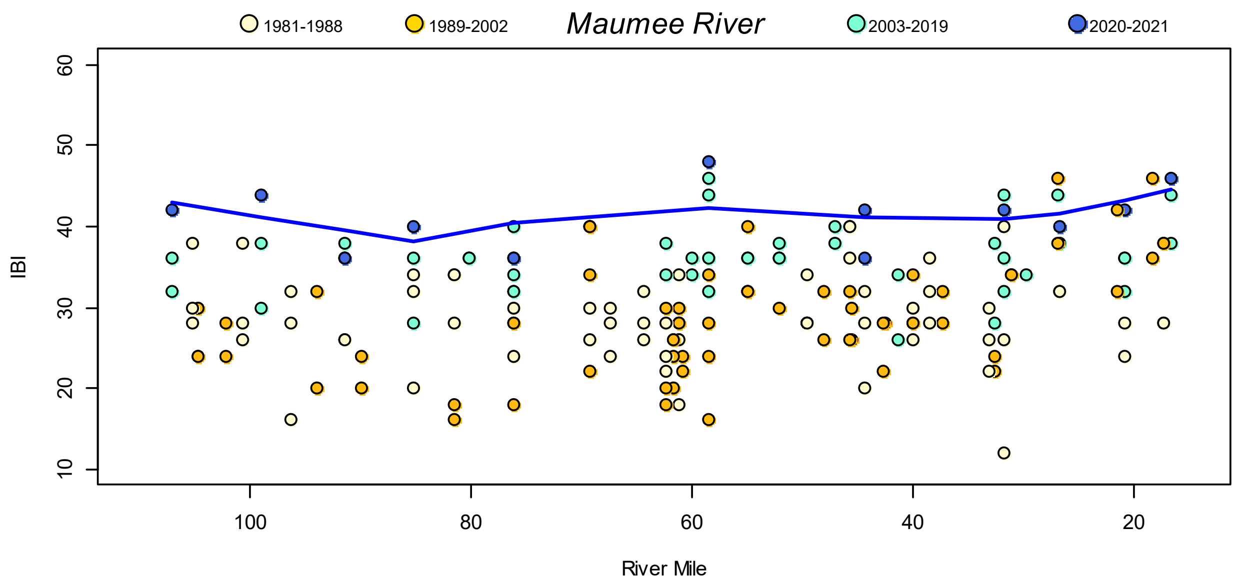
Relationship between barium, pheophytin, and modeled Invertebrate Community Index scores (from boosted regression).

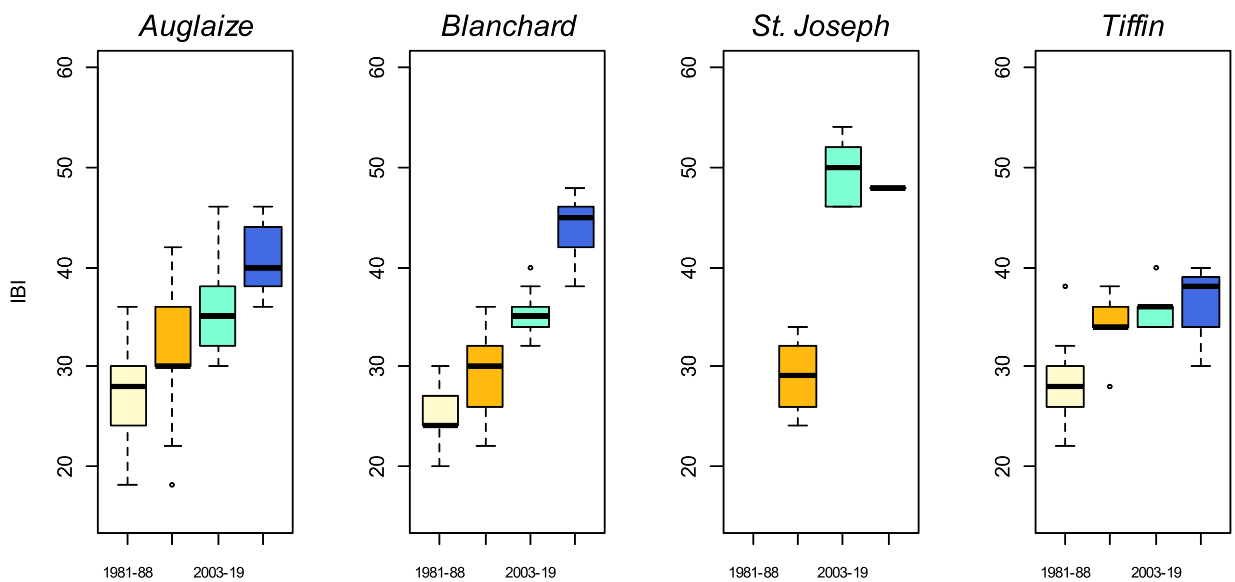
Trends in biotic index scores by river.

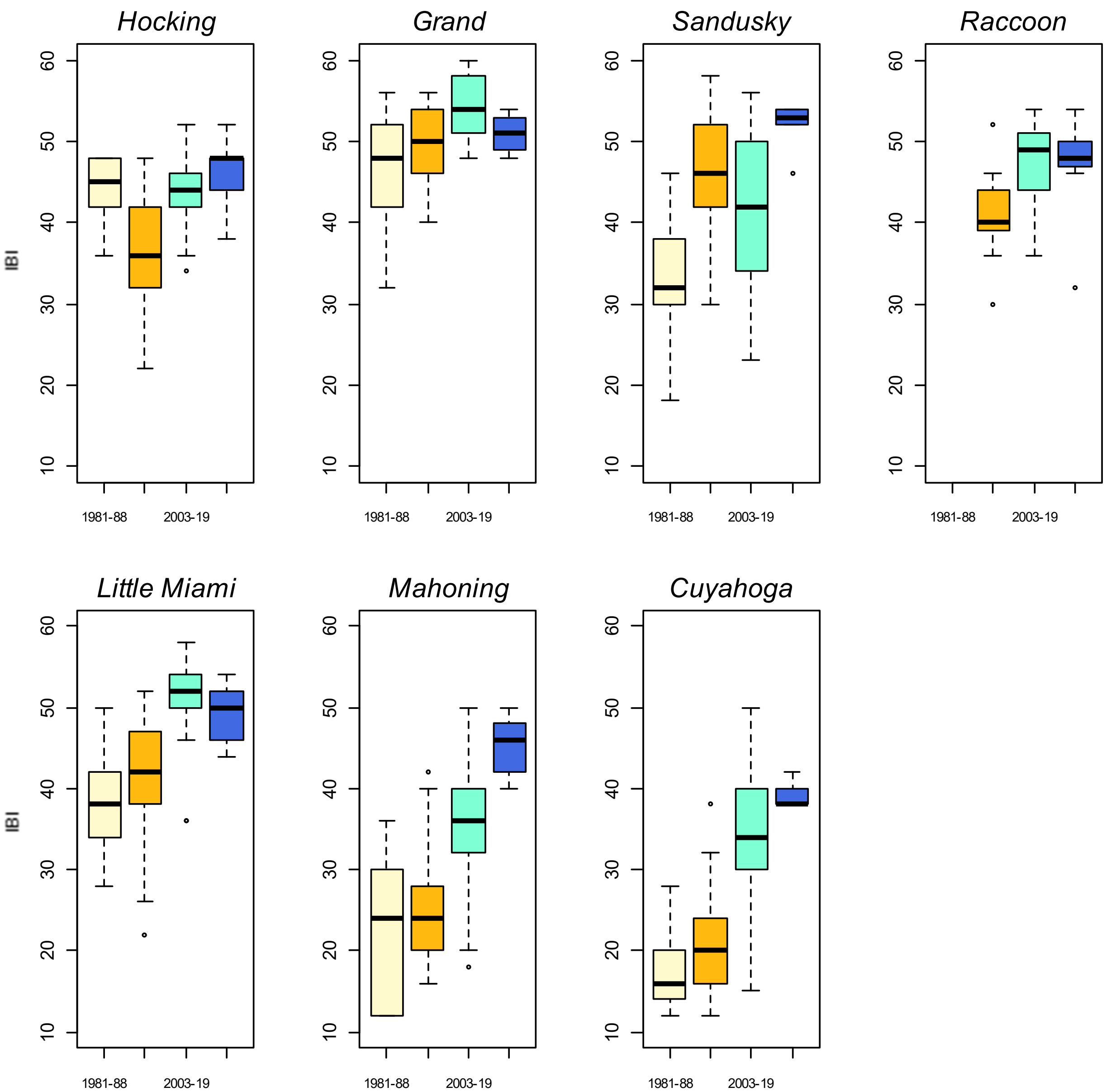


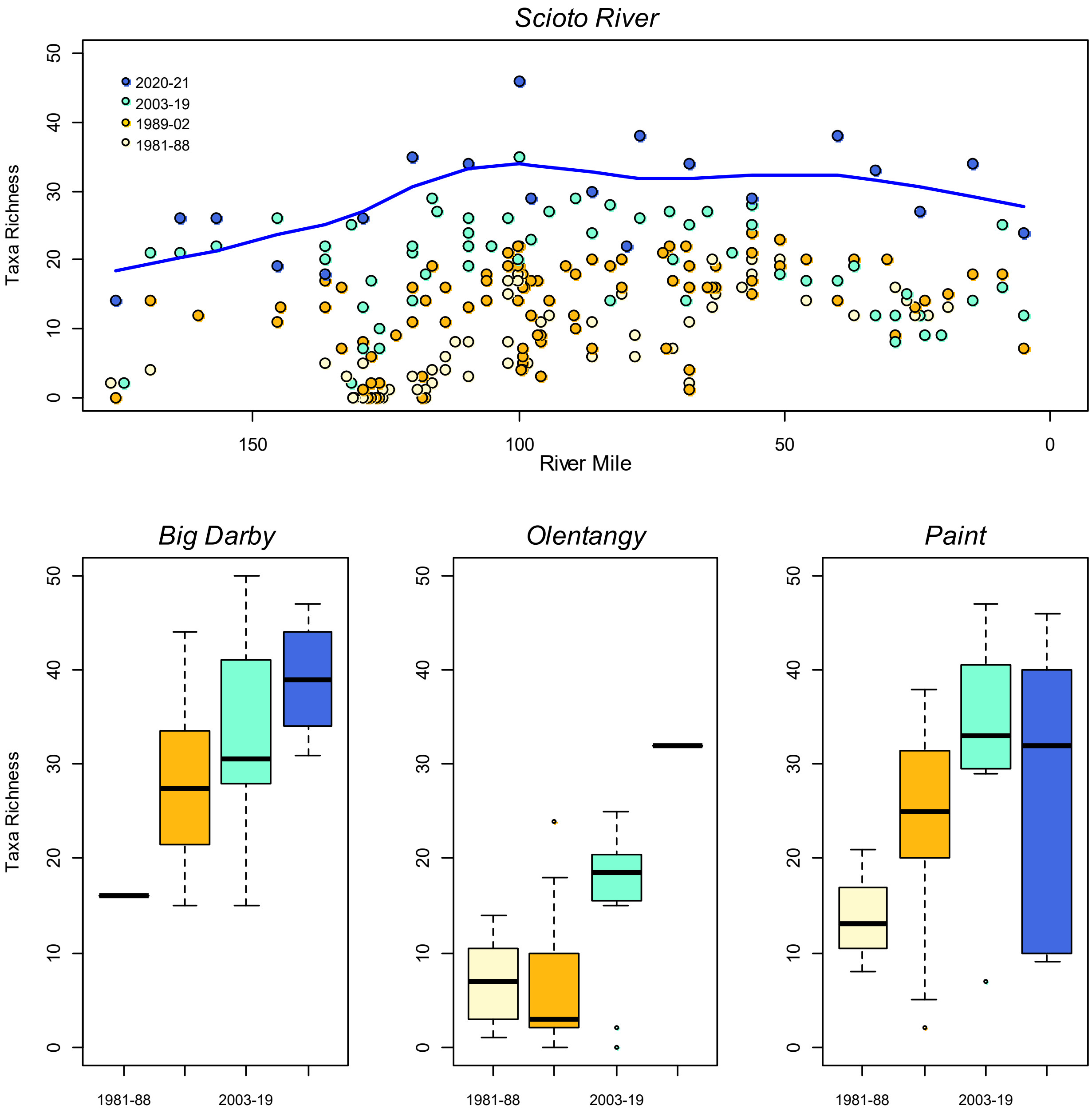

Muskingum River
IBI
60
50
40
30
20
10
100
80
60
40
20
0
Tuscarawas River
1981-1988
1989-2002
2003-2019
2020-2021
River Mile
Licking
Walhonding & Mohican
Killbuck
Wills
1981-88
2003-19

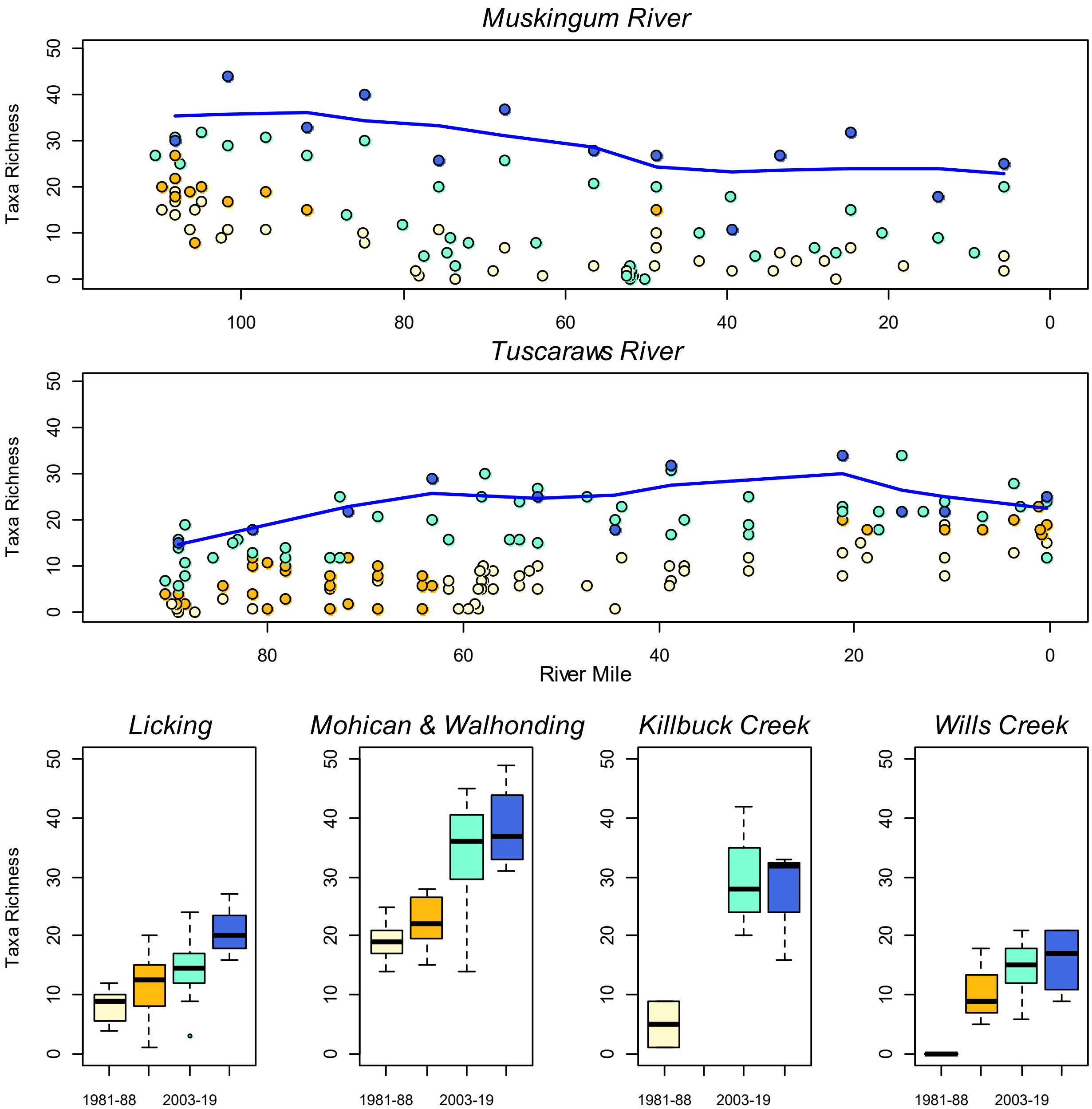

1981-1988
1989-2002
Great Miami River
2003-2019
2020-2021
IBI
River Mile
Mad
Stillwater
Whitewater
IBI
1981-88
1989-02
2003-19
2020-21

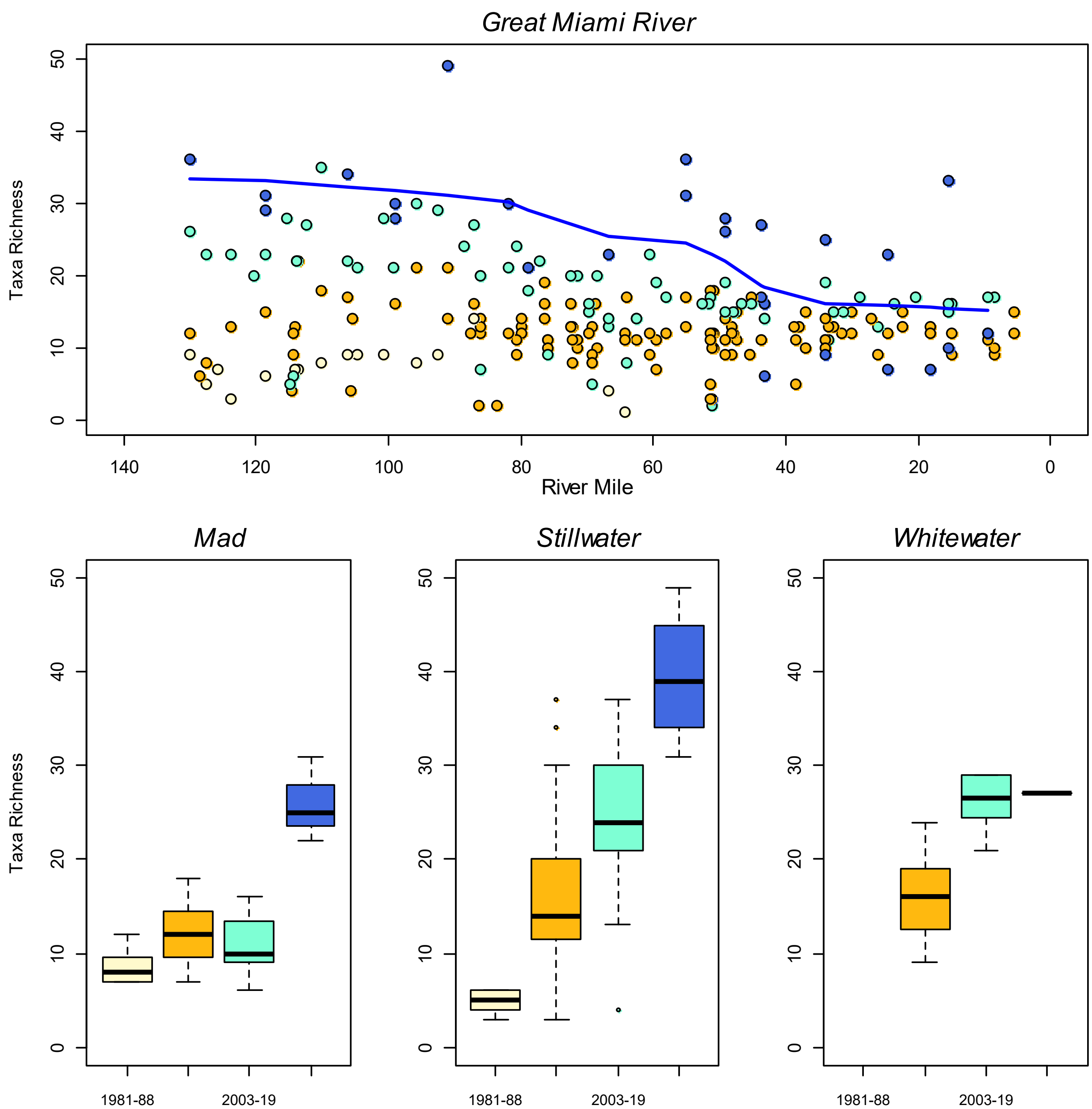

1981-1988
1989-2002
Maumee River
2003-2019
2020-2021
IBI
River Mile
60
50
40
30
20
10
100
80
60
40
20

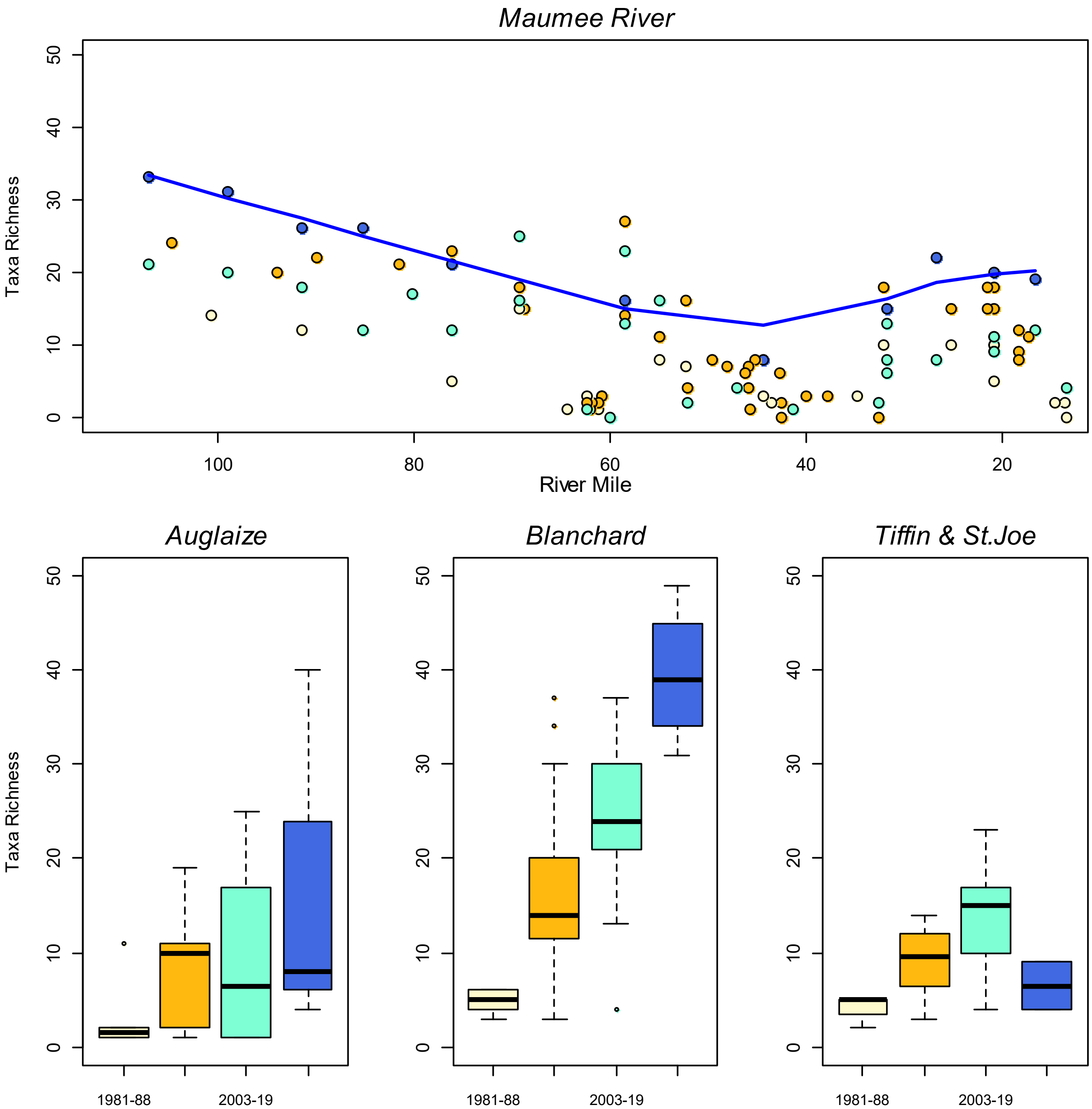

Auglaize
Blanchard
St. Joseph
Tiffin
IBI
1981-88
2003-19

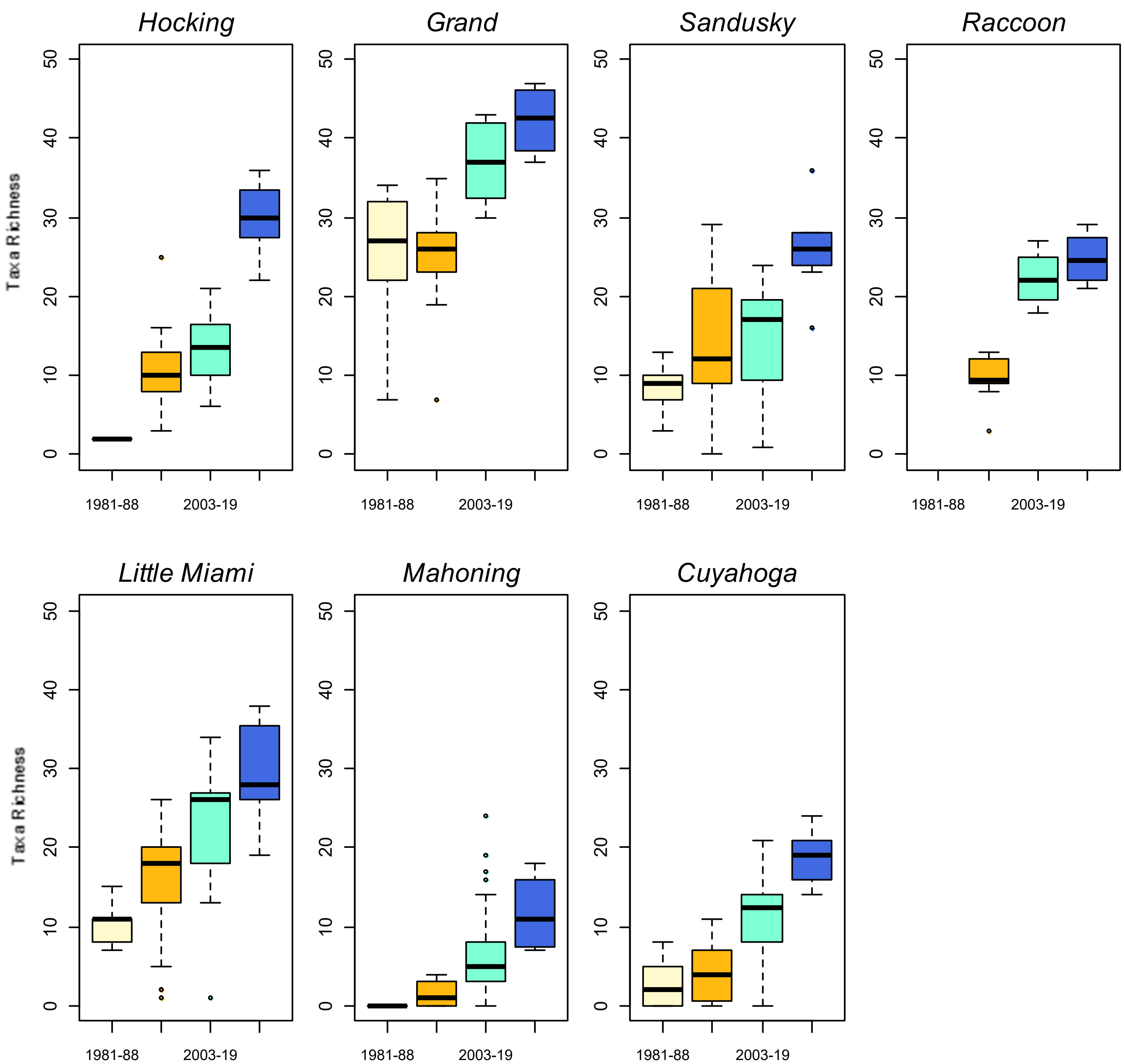

Hocking
Grand
Sandusky
Raccoon
Little Miami
Mahoning
Cuyahoga
IBI
10
20
30
40
50
60
1981-88
2003-19


Scioto River
Taxa Richness
River Mile
2020-21
2003-19
1989-02
1981-88
Big Darby
Olentangy
Paint
1981-88
2003-19


Muskingum River
Taxa Richness
Tuscaraws River
Taxa Richness
River Mile
Licking
Mohican & Walhonding
Killbuck Creek
Wills Creek
Taxa Richness
1981-88
2003-19


Great Miami River
Taxa Richness
River Mile
Mad
Stillwater
Whitewater
1981-88
2003-19


Maumee River
Taxa Richness
River Mile
Auglaize
Blanchard
Tiffin & St.Joe
1981-88
2003-19


Hocking
Grand
Sandusky
Raccoon
Little Miami
Mahoning
Cuyahoga
Taxa Richness
0
10
20
30
40
50
1981-88
2003-19