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Temporal Change in Regional Reference Condition as a Potential Indicator of Global Climate Change: Analysis of the Ohio Regional Reference Condition Database (1980-2006)

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Temporal Change in Regional Reference Condition as a Potential Indicator of Global Climate Change: Analysis of Ohio Regional Reference Condition Over 30 Years

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Introduction

Global climate change is clearly one of the most important and controversial areas of contemporary environmental science. Given that global climate change is occurring and affecting biota (Root et al. 2003; Walther et al. 2002), it is important to understand the ramifications of climate change on the application of environmental monitoring data to environmental management actions. States have widely adopted biological assemblage data as the most accurate and representative indicator of attainment and impairment of Clean Water Act (CWA) aquatic life use designations. Most states have used reference sites to support the development and derivation of biological criteria and at least three states have adopted numeric biocriteria into their water quality standards (WQS). If global climate change is influencing reference condition, then it would be useful to distinguish the effects of global climate change from other anthropogenic stressors and/or natural variations that also affect it. The need to determine if the effects of global climate change are ecologically relevant requires the ability to distinguish among natural variation and anthropogenic stressors that are potentially influencing aquatic assemblages when developing and deriving biological criteria for aquatic life uses.

U.S. EPA developed the “Biological Condition Gradient” (BCG) concept as a basis for supporting the development tiered aquatic life uses for streams and rivers (Figure 1; U.S. EPA 2005; Davies and Jackson 2006). Anchored in the naturally occurring state of a specific aquatic ecotype the BCG describes how the biological assemblage attributes change with increasing effects from stressors. As such the BCG fulfills two functions: 1) it organizes our knowledge about how biological assemblages change along a generalized stressor gradient; and, 2) it provides a scale for assigning meaningful and attainable

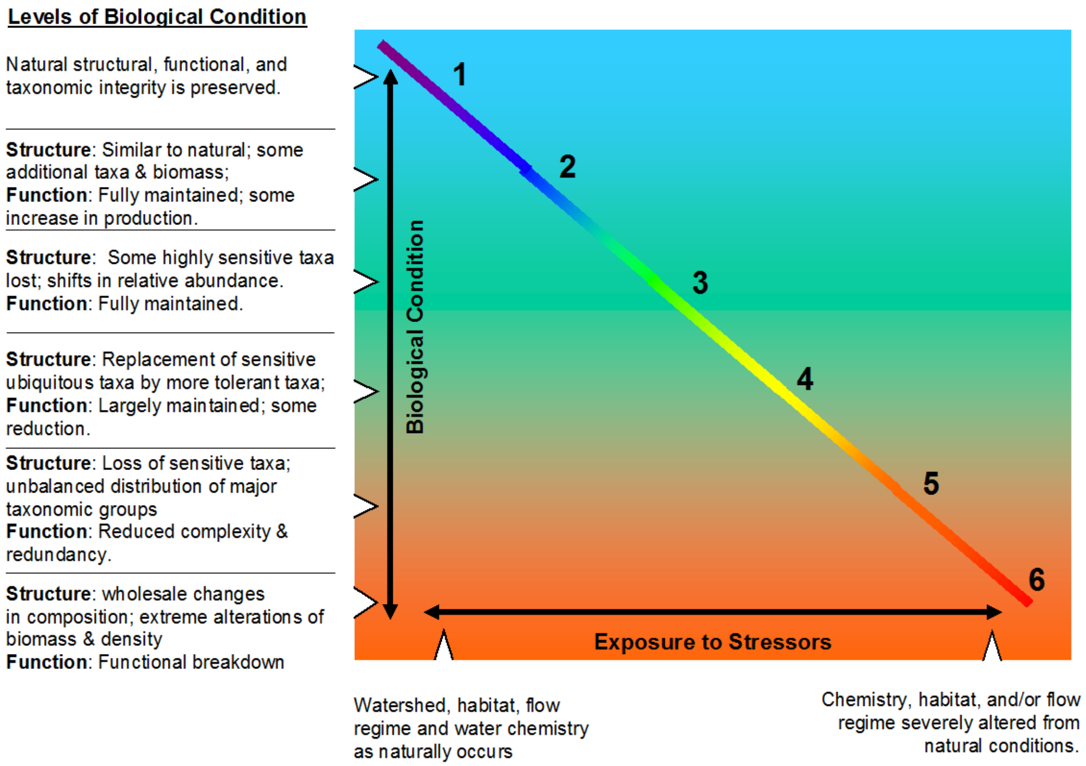

Figure 1. The Biological Condition Gradient (BCG) conceptual model and descriptive attributes of tiers along a gradient of quality and increasing disturbance (U.S. EPA 2005; Davies and Jackson 2006).

thresholds for designating tiered aquatic life uses that correspond to the attributes of the BCG.

Reference Condition

A key ingredient involved in the convergence of the two major aspects of the BCG is reference condition. Stoddard et al. (2006) provide standardized definitions of reference terminology that includes important distinctions between the “as naturally occurs” or unimpacted conditions at the upper end of the BCG and “minimally impacted” to “least impacted” to “best attainable” conditions that occur below BCG tier 1. Reference conditions as used by states with a high level of background land use disturbance or other watershed alterations are not consistent with “as naturally occurs” but most often are defined by least impacted or best attainable conditions. Because reference condition provides the empirical data for deriving and calibrating biological indices and is also used to extract numerical biological criteria for designated aquatic life use tiers, it is important to consistently monitor reference sites to determine whether reference conditions are changing through time. For example, certain widely applied management actions could eventually result in detectable improvements in reference condition. Conversely, the appearance or increase in the spatial scope of "new" stressors (e.g., suburbanization, changes in agricultural related stressors, climatic changes, etc.) could result in a general decline in reference condition. How states would factor these changes into their biological criteria and WQS has not yet been encountered. However, the lowering of biological criteria expectations for CWA goal uses in response to widespread declines in reference condition would not be consistent with federal water quality regulations[1].

Ohio EPA Regional Reference Database – Background

Ohio was one of the early states to systematically use biological assemblage data to determine aquatic life use designations and assess the condition of those uses dating back to the late 1970s. Ohio implemented standardized sampling methods for biological assessments early on (late 1970s) hence their data represent a nearly thirty year span of standardized biological data for two assemblage groups. From the late 1970s to 2006 the Ohio fish assemblage database represents >10,000 unique sites and >24,000 unique sampling events; macroinvertebrate assemblage data were also collected at most of these same sites. Qualitative Habitat Evaluation Index (QHEI) data has also been included at the fish sites (Ohio EPA 2006; Rankin 1989, 1995). While the QHEI is visually based, our recent analyses have shown it to be as precise as a quantitative habitat assessment tool to which it was compared (Miltner et al. 2009; Rankin, in preparation). Our purpose here is to analyze any changes in the reference dataset that could represent signal or lack of signal related to the effects of global climate change.

In the 1980s and with assistance from U.S. EPA-ORD, Ohio EPA began a focused sampling of least impacted reference sites in order to determine the efficacy of level III ecoregions (Omernik 1987) as a way to account for and stratify natural variations in biological assemblages (Ohio EPA 1987a; Whittier et al. 1987; Yoder 1989). Ohio EPA used this and other sampling data to establish a network of "least impacted" regional reference sites that eventually supported the derivation of numerical biocriteria for Ohio streams and rivers. This was also accomplished across all practically sampleable stream and rivers from >1 mi^2 up to the largest inland rivers (~6000-8000 mi^2). This includes both wadeable and non-wadeable. Fish assemblage indices were stratified by three stream and river size strata; headwater streams (<20 mi^2), "wadeable" streams (20 -~300 mi^2), and "boatable" (i.e., non-wadeable) rivers (>~150-200 mi^2) (Yoder and Rankin 1995). Macroinvertebrate assemblage indices were calibrated continuously across the entire range of stream and river sizes. The initial reference dataset was developed from a statewide network of about 300 reference sites that was sampled over a ten year period (1980-89; Table 1). That reference site network was maintained and expanded with the initial resampling during 1990-99 and a second resampling that will be completed at the end of 2009 (2000-09). Data on habitat quality (QHEI), water quality, and other physical data such as temperature were also collected and were based on multiple grab samples collected during "normal" seasonal flows within a summer-fall seasonal index period (mid-June through mid-October).

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[1] This is prohibited by the "existing use" clause in the federal water quality regulations (40CFR Part 131).

Table 2. Summary of Ohio EPA regional reference site network including original sites (1980-89) and updates via first (1990-99) and second round resampling (2000-06) that were used in our data analyses.

Reference Network	Size Type	Fish: Latest (All Data)	Macroinvertebrates
Original Reference Sites: 1980-89 (Sites/Samples)	Headwaters	112/225	242
	Wadeable	166/399	
	Boatable	97/254	
New Reference Sites: 1990-2006 (Sites/Samples)	Headwaters	115/(149)/150 (296)	309 (525)
	Wadeable	184(231)/281(539)	
	Boatable	68(84)/127(278)	

Signals of Global Climate Change

While there is substantial direct and indirect evidence for global climate change in areas that are thought most susceptible to such changes (e.g., Polar Regions, high altitudes) little is known or expected from temperate climate biomes such as the Midwestern U.S. There are generally three areas of focus with regard to detecting the effects of climate change: 1) changes in species distribution and ranges; 2) changes in phenology (e.g., date of emergence for macroinvertebrates, spawning dates for fish); and 3) changes in evolutionary effects due to altered selection regimes from temperature, flow, etc (U.S. EPA 2008). The usefulness of the long term biological dataset from Ohio is largely focused on the first of these focal areas and the usefulness of the biological criteria assessment data and tools that are presently used to detect and then understand assemblage or distributional shifts.

While it is important to understand the ramifications of climate change and have evidence from a variety of habitat types and biomes, biological evidence from streams and rivers has been rather sparse (Daufresne et al. 2004; Durance and Ormerod 2007). Circumstantial evidence of global climate change in the Midwest includes an extended growing season, shortened winters, increased annual average temperatures, more extreme heat events, earlier ice out, and changes in precipitation patterns (!!need refs!!). It would be logical to assume that these also have been accompanied by increased ambient water temperatures. However, indirect effects of these climatic changes may also be manifest in changes to the hydrological regime and indirectly to the other factors this important variable can influence such as water quality and habitat (Figure 2). Needless to say documenting trends of increase or decrease in any single parameter is made difficult by the intra and inter-annual variability of each. Changes in biological assemblage condition, however is likely to be more stable and thus easier to detect.

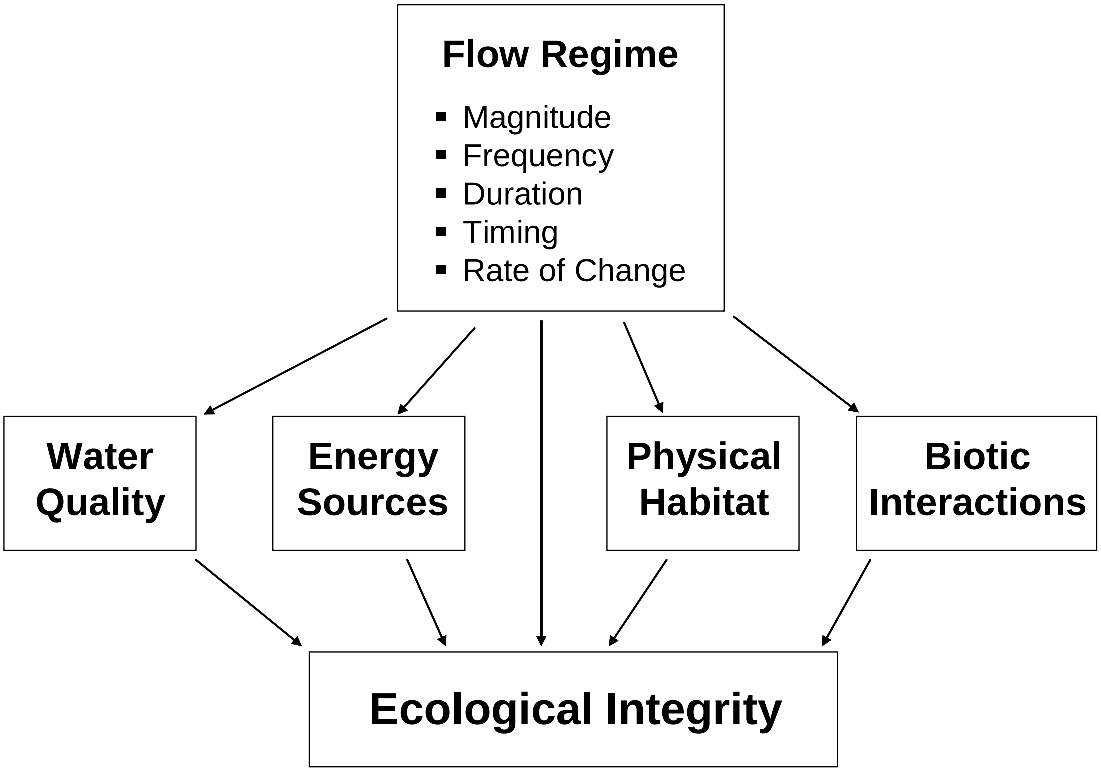


Figure 2. The central importance of flow regime to the ecological integrity of a lotic ecosystem (after Karr 1991).

Data Analyses

Our primary goal is to examine the Ohio reference database for trends and the entire dataset for candidate indicators of climate change. Important effects of global climate change include changes in not only temperature, but also rainfall patterns and resulting hydrological regimes in Ohio streams and rivers thus we also explored the usefulness of using the QHEI as an indirect measure of hydrological change.

Trends in Ohio Reference Sites

We conducted an initial exploration of Ohio's reference database to determine whether biological reference condition has changed over time since 1980. This analysis directly overlapped with an Ohio EPA sponsored effort to conduct the initial data analysis steps for the recalibration of the Ohio biocriteria (Rankin 2008). Of particular importance to our analyses is the examination of trends in biological condition at the reference sites and exploring the potential causes that are associated with the observed changes. As such it is essential to understand the environmental changes that have also occurred that could potentially confound any signals of climate change related effects. Based on nearly thirty years of intensive watershed assessments Ohio EPA has identified a variety of environmental changes that are associated with shifts in biological condition at the assemblage and species/taxa levels. Such environmental changes include; 1) a reduction in point source loadings (particularly important in non-wadeable rivers where some reference sites are necessarily downstream of point sources), changes in land uses (e.g., increased urbanization), changing loadings of pollutants from agricultural lands (e.g., declining sediments and nutrients in response to increased conservation tillage), habitat changes (e.g., loss of habitat quality from agricultural drainage practices [common], suburbanization [common], improved habitat quality resulting stream restoration [rare and localized]), and potential climate change related influences from changes to the temperature and/or hydrological regimes. These latter changes, if any, may be the most difficult to detect due to the lack of readily available long term data for temperature and flow and the indirect actions of any adverse impacts. It is first important to identify any methodological differences in data collection (environmental and biological) that could either confound or mask apparent trends. In the Ohio dataset this is most likely represented by taxonomic refinements from an improving resolution in the identification of macroinvertebrates over the past 30 years. Thus we included some initial explorations and recommendations related to this factor for the Ohio data set. We focused primarily on the mayflies because they are an important component of the Ohio ICI, taxonomic refinements are known to have occurred, and taxonomic refinements would be expected to influence multiple metrics (total taxa, mayfly taxa, qualitative EPT taxa, etc.).

Taxonomic Analyses

We used the entire Ohio database to identify "earliest" and "latest" years for all taxa in order to extract a list of possible taxa that could affect ICI scoring via taxonomic refinement (splitting or lumping of taxa). We focused on the mayfly taxa at reference sites and identified taxa and sites that occurred in the original reference sites, but not the new sites and visa versa. Table 2 lists all mayfly taxa collected at the Ohio reference sites that appeared earlier and then "disappeared" ("earlier") or those that "appeared" later, mostly at resampled reference sites ("later"). We then conferred with senior Ohio EPA taxonomists (Mike Bolton and Jack Freda, Ohio EPA) and determined whether any of these taxa are purely a result of taxonomic changes made in the intervening time. These taxa were identified (Table 2) and the ICI recalculated with the same taxon designations as for the original references sites in order to attribute any changes in the total taxa metric, the mayfly metric, and the qualitative EPT metric to observed changes in the ICI. This effort primarily consisted of "lumping" individual taxa designations of mayfly taxa back to "Baetis sp." or "Pseudocloeon sp." (Table 2).

Weighted Stressor Values (WSVs)

Candidate fish and macroinvertebrate taxa that could serve as indicators of climate change (sensitive to temperature or other measures such as hydrological stressors) were determined from weighted stressor values (WSVs) and "Taxa Indicator Values" (TIVs) for temperature and habitat measures that would be correlated with hydrological alterations. The WSVs were generated by relating historical taxa/species from sites in Ohio to chemical and habitat stressors and calculating weighted average values for each taxa/stressor combination where the weighting is the relative abundance of the taxa/species at a site. TIV values for

Table 2. Mayfly taxa from reference sites in Ohio that abruptly appeared (Later) or disappeared (Earlier) in the Ohio dataset and explanation of change. Explanations were provided by Mike Bolton and Jack Freda of Ohio EPA.

Taxa Code	Taxon Name	Appearence	Explanation of Change
11010	Acentrella sp	Later	Improved taxonomy allow this taxa to be distinguished Pseudocloeon sp.
11014	Acentrella turbida	Later	Improved taxonomy allow this taxa to be distinguished from Pseudocloeon sp.
11015	Acerpenna sp	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11018	Acerpenna macdunnoughi	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11020	Acerpenna pygmaea	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11110	Acentrella parvula	Later	Improved taxonomy allow this taxa to be distinguished from Pseudocloeon sp. or was renamed from Pseudocloeon parvulum
11115	Baetis tricaudatus	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11118	Plauditus dubius	Later	Improved taxonomy allow this taxa to be distinguished Pseudocloeon sp.
11119	Plauditus dubius or P. virilis	Later	Improved taxonomy allow this taxa to be distinguished Pseudocloeon sp.
11120	Baetis flavistriga	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11125	Pseudocloeon frondale	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11130	Baetis intercalaris	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11150	Pseudocloeon propinquum	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11155	Plauditus punctiventris	Later	Improved taxonomy allow this taxa to be distinguished Pseudocloeon sp.
11175	Plauditus virilis	Later	Improved taxonomy allow this taxa to be distinguished Pseudocloeon sp.
11250	Centroptilum sp (w/o hindwing pads)	Later	Improved taxonomy allow this taxa to be distinguished Cloeon sp.
11400	Centroptilum sp or Procloeon sp (formerly in Cloeon	Earlier	Improved taxonomy allow this taxa to be distinguished Cloeon sp.
11430	Diphetor hageni	Later	Improved taxonomy allow this taxa to be distinguished from Baetidae sp.
11503	Heterocloeon curiosum	Later	Renamed Heterocloeon (H.) sp, Heterocloeon sp.
11600	Paracloeodes sp 1	Later	Improved taxonomy allow this taxa to be distinguished from Paracloeodes sp
11625	Paracloeodes sp 3	Later	Improved taxonomy allow this taxa to be distinguished from Paracloeodes sp
11645	Procloeon sp	Later	Was earlier classified as Centroptilum sp or Cloeon sp
11650	Procloeon sp (w/ hindwing pads)	Later	Was earlier classified as Cloeon sp
11651	Procloeon sp (w/o hindwing pads)	Later	Was earlier classified as Centroptilum sp
11670	Procloeon irrubrum	Later	Improved taxonomy allow this taxa to be distinguished from Cloeon sp
11700	Acentrella sp or Plauditus sp (formerly in Pseudoc	Earlier	Renamed as Pseudocloeon sp
13010	Leucrocuta hebe	Earlier	Renamed as Heptagenia hebe
13030	Leucrocuta maculipennis	Earlier	Renamed as Heptagenia maculipennis
14501	Leptophlebiidae	Earlier	Now coded as Leptophlebia sp
14900	Leptophlebia sp	Later	Leptophlebia sp
14950	Leptophlebia sp or Paraleptophlebia sp	Later	Small specimens lumped

taxa were then ranked from most to least sensitive for each of the pertinent parameters and converted to an ordinal scale of 1-10 where 1 is the most sensitive and 10 the most tolerant following the methodology of Meador and Carlisle (2007). WSVs were then plotted vs. a simple means code by Ohio taxa/species tolerance designations to identify the indicator taxa that occur at the extremes of the distributions.

QHEI Data

QHEI includes the habitat attributes of substrate, cover, channel, riparian, pools, riffle, and stream gradient (Rankin 1989, 1995). Recent analyses of the OHEI shows it to be relatively precise (Miltner et al. 2009) and it has been collected by trained professionals since its inception by Ohio EPA. We used a subset of the metric components to create a sub-index (Hydro-QHEI) that extracts the habitat attributes that are responsive either directly (current speed components) or indirectly (stream depth measures) to alterations of the flow regime. Scoring calculations for the Hydro-QHEI are detailed in Table 3. Hydro-QHEI ranges from 0 to 25 and includes the two QHEI subcomponents most related to hydrology, current and depth. We used the Hydro-QHEI and its two subcomponents to

Table 3. Sub-components of the Ohio QHEI which were used to score a Hydro-QHEI and current and depth sub-scores.

Current Metric		**Depth Metric**	
QHEI Current Attribute	Score	QHEI Depth Attribute	Score
Very Fast Current	+5	Deep Pools (Cover Metric)	+4
Fast Current	+3	Pool Depths > 1m	+4
Moderate Current	+2	Pool Depths 0.7 – 1.0 m	+3
Slow Current	+1	Pool Depths 0.4 – 0.7 m	+2
Eddies	+2	Pool Depths 0.2 – 0.4 m	+1
Very Deep Riffles	+3	Pool Depths < 0.20	-1
Moderate Depth Riffles	+1	Deep Riffles	+3
Interstitial Flow	-1	Moderate Riffles	+2
Intermittent Flow	-3	Shallow Riffles	+1
		Riffles Absent or Non-functional	-1

detect any trends in these components over time as evidence for potential effects from hydrological alterations. We also calculated WSVs for these components to identify taxa/species that could be sensitive to hydrological changes in Ohio.

Results

Potential Trends in Ohio Reference Sites

Some of the following analyses were conducted for Ohio EPA in an initial assessment towards re-calibrating Ohio EPA's biocriteria based on data after 1988 (Rankin 2008) and attached as Appendix 1. Ohio's original reference site data was collected between 1978 and 1988. Table 4 summarizes the ranges of years that represent the universe of original and re-sampled reference sites. For analyzing trends in reference sites we used the latest data available for calculating updated biocriteria statistics. On average the latest data period was 13-16 years after the mean of the original reference sample dates (Table 4).

Table 4. Average and range of years represented by original reference site data and re-sampled (latest) data by index and stream size category pertaining to fish samples.

Index/Stream Size	Mean Year Sampled (Range)	
	Original Reference Sites	Re-Sampled Sites
ICI – All Sites	1984 (1980-1988)	2000 (1989-2007)
IBI - Headwaters	1984 (1978-1988)	2000 (1989-2006)
IBI - Wading	1984 (1979-1988)	2000 (1990-2006)
IBI - Boat	1984 (1979-1988)	1997 (1990-2005)

Table 5 reports the original biocriteria values and statistics, a re-calculation of those statistics using refined variables, and "new" biocriteria values based on the latest re-sampled reference sites. Because possible IBI or ICI scores based on single samples are always even values, calculated percentile values were rounded upwards (e.g., 41 to a 42). Discrepancies between the original calculations and our recalculations are highlighted in yellow. The original biocriteria statistics were re-calculated in the database because there are a few minor discrepancies related to uncertainties about the exact membership of the original reference sites and gradual changes made to the database since 1990 due to changing taxonomy and a more precise calculation of drainage area (Rankin 2009).

Table 5. Original Ohio biocriteria (O), recalculated biocriteria (R) using similar sites, and new biocriteria (N) using the latest data from re-sampling of original reference sites. Sites with discrepancies between original and recalculated criteria are highlighted in yellow.

Ecoregion	Modified Warmwater Habitat (MWH)									WWH			EWH		
	Channelized			Non-Acidic Mine Drainage			Impounded								
IBI – Headwater Site Type															
	O	R	N	O	R	N	O	R	N	O	R	N	O	R	N
HELP	20	20	26							28	-	-	50	50	52
IP	24	24	26							40	40	40			
EOLP										40	38	36			
WAP				24	24	a				44	44	42			
ECBP										40	40	44			
IBI – Wadeable Site Type															
HELP	22	22	22							32	-	-	50	50	52
IP	24	24	30							40	40	44			
EOLP	24	24	30							38	38	42			
WAP	24	24	30	24	24	32				44	44	46			
ECBP	24	24	30							40	40	40			
IBI – Boatable Site Type															
HELP	20	20	20				22	22	26	34	30 34	30 34	48	48	52
IP	24	24	24				30	28	34	38	38	47			
EOLP	24	24	24				30	28	34	40	40	46			
WAP	24	24	24	24	24	26	30	28	34	40	40	40			
ECBP	24	24	24				30	28	34	42	42	42			
MIwb – Wadeable Site Type															
HELP	5.6	5.9	6.4							7.3	-	-	9.4	9.4	9.5
IP	6.2	6.4								8.1	8.1	8.1			
EOLP	6.2	6.4								7.9	7.9	8.2			
WAP	6.2	6.4		5.5	4.7	6.1				8.4	8.3	8.8			
ECBP	6.2	6.4								8.3	8.3	7.8			
MIwb – Boatable Site Type															
HELP	5.7	5.7	7.5[a]				5.7	5.7	7.4	8.6	-	-	9.6	9.6	10.2
IP	5.8	5.7	6.1[a]				6.6	7.0	7.5	8.7	8.7	9.6			
EOLP	5.8	5.7	6.1[a]				6.6	7.0	7.5	8.7	8.8	8.9			
WAP	5.8	5.7	6.1[a]	5.4	5.4	6.4	6.6	7.0	7.5	8.6	8.6	9.2			
ECBP	5.8	5.7	6.1[a]				6.6	7.0	7.5	8.5	8.5	9.7			

Table 5. (continued)

ICI – All Site Types Combined															
HELP	22	22	24							34	34	42	46	46	50
IP	22	22	24							30	30	38			
EOLP	22	22	24							34	34	44			
WAP	22	22	24	30	30	26				36	36	40			
ECBP	22	22	24							36	36	42			

a – Non-acidic mining influenced modified sites for headwaters combined with wading sites due to small sample size.

The direction of change in the biocriteria between the original and latest reference site data was either positive (an increase) or neutral (no change) with only three instances where the new biocriteria were lower. These included: 1) the ICI biocriterion for the non-acidic mine drainage modified use (-4 pts; possible small sample size); 2) the IBI for WWH headwater site type in the EOLP ecoregion (-2 pts); and, 3) the IBI for WWH headwater site type in the WAP ecoregion (-2 pts). None of these changes are considered to be greater than the non-significant departure for each index.

The direction of climate related changes in biological index scores could be in either direction. However, the most plausible expectation would be for a decline due to the immediate loss of highly intolerant species and taxa (i.e., temperature and flow sensitive taxa/species) and a co-occurring increase in intermediate, moderately, and/or highly tolerant taxa/species. Such expectations are supported by our analyses that identify a general concordance between intolerant and sensitive species as categorized for the IBI and ICI and species sensitive to temperature and habitat features indicative of altered flow conditions (see Appendix 3).

The largest positive changes in the biocriteria were in the WWH boatable fish sites (IBI and MIwb) and in the WWH ICI. The fish assemblage changes in large rivers are most attributable to reduced pollution from point sources, mostly due to municipal wastewater treatment plant upgrades after 1988 (Yoder et al. 2005). While it was necessary in the derivation of the original Ohio IBI for boatable sites to include reference sites located in effluent dominated rivers, the sites were positioned below known recovery points. Nevertheless, the lessening of secondary impacts from nutrient enrichment by the aforementioned controls had positive effects on the fish assemblages at these reference sites. Taxonomic changes in fish nomenclature did not influence IBI scores between these time periods nor did the fish sampling technology as the methodology and equipment was generally stable between these time periods.

Influence of Taxonomic Changes on Trend Assessment in Ohio

The question concerning the relative contribution of taxonomic changes to the macroinvertebrate assemblage trends in the Ohio biocriteria values at reference sites was also examined during this phase of the data analysis. While fish data can be influence by factors such as sampling efficiency, their taxonomy has been comparatively stable during the period over which the Ohio reference database was developed. As for sampling methodology, methods used by Ohio EPA for both fish and macroinvertebrates have been stable over the period of the Ohio reference database. However, there have been significant changes in macroinvertebrate taxonomy over this time period mostly in the form of an improved discrimination within certain genera (e.g., Baetid mayflies) that could result in changes to the ICI "number of" metrics for mayflies and other taxonomic groups that are also identified to more refined taxonomic resolution.

We developed a program to scan the Ohio EPA database and identify taxa that may have been revealed by improved taxonomy which would result in two or more taxa in lieu of a single taxon. This program resulted in a listing of all taxa and the first and last occurrence of each taxon in the Ohio EPA database (Appendix 1). We then focused on the taxonomic changes in mayflies to examine the quantitative contribution of the refined taxonomy on ICI scoring for three metrics; total taxa, mayfly taxa, and qualitative EPT taxa. We then recalculated the mean number of taxa for each metric as it now occurs in the database ("refined" taxonomy) and then again with the taxonomy "lumped" to match the level of taxonomy that was prevalent during the derivation of the original biocriteria (Table 5). We also recalculated the biocriteria statistics (25th percentiles by ecoregion for WWH; 75th percentiles statewide for EWH) based on the newly refined and lumped taxonomy (Table 6).

The recalculation of ICIs from all sites indicated a 5.9 point increase in the mean ICI score between the two time periods. When mayfly taxonomy was lumped between these time periods the increase was 5.0 showing that taxonomic refinement in mayflies accounted for 14% of the increase in the mean ICI between the two reference time periods (Table 6). Only two cases showed a change in the biocriteria the HELP WWH biocriterion (38.5 compared to 42) and the EOLP WWH biocriterion (42 compared to 44).

The changes in mayfly taxonomy reflect the greatest influence on ICI scoring in the Ohio database; other taxa would likely have a lesser impact compared to the impact on mayfly metrics (Jack Freda, personal communication). Future work should isolate all of the other taxonomic refinements that could confound trends in metrics and index scores. Comparisons of similarity of macroinvertebrate taxonomy in samples between European countries concluded that taxonomic adjustments prior to analyses of the separate data sets reduced species richness from 45 to 81% by country and 85% for all countries combined (Verdonschot and Nijboer 2004). We are dealing with much smaller changes in the Ohio database.

Table 6. Changes in ICI and mayfly influence ICI metrics related to increasing taxonomic resolution over time in the Ohio EPA least impacted reference data set.

Metric	Original Reference Sites		New Reference Sites (Latest Data)	
	Standard Taxonomy Mean Taxa (Mean Score)	Lumped Taxonomy Mean Taxa (Mean Score)	Standard Taxonomy Mean Taxa (Mean Score)	Lumped Taxonomy Mean Taxa (Mean Score)
Total Taxa	35.97 (4.89)	35.93 (4.89)	38.36 (5.18)	37.65 (5.04)
Number of Mayfly Taxa	6.95 (4.20)	6.90 (4.17)	7.42 (4.59)	6.59 (4.16)
QUAL EPT Taxa	11.29 (3.63)	11.24 (3.60)	15.16 (5.16)	14.23 (4.91)
ICI Score	39.59	39.53	45.35	44.56

Table 7. Table of original and recalibrated Ohio biocriteria with adjustments made to equilibrate taxonomic advances made in the later time period. Highlighted cells indicate where standardizing taxonomic resolution would have resulted in altered criteria.

	Warmwater Habitat			Exceptional Warmwater Habitat		
Ecoregion	Original Reference	Latest Reference	Latest Reference w/ Refined Taxonomy	Original Reference	Latest Reference	Latest Reference w/ Refined Taxonomy
HELP	34	42	38.5	46	50	50
IP	30	38	38			
EOLP	34	44	42			
WAP	36	40	40			
ECBP	36	42	42			

Weighted Stressor Values (WSVs)

We calculated WSVs for maximum temperature and Hydro-QHEI variables separately for headwater streams (drainage area ≤20 mi.^{2}) and wadeable streams (drainage area >20 to 300 mi.^{2}); these are listed in Appendix 1. These data are ordered by WSV for each parameter to provide a sequential listing of sensitive species/taxa that can be used to detect trends in relation to temperature or flow alterations. It also provides a listing of tolerant species that might increase in predominance if temperature were to increase or the hydrological regime became increasingly variable.

Temperature

We used the maximum temperature recorded from summer-fall grab samples collected during the same period within which the biological data were collected to calculate WSVs for headwater and wadeable streams. To visualize the distribution of this data with taxa sensitivities we plotted the means of these values vs. the weighted means (WSVs) color coded by the existing taxa tolerance rankings of Ohio EPA (Figure 3). Because the temperature indicator was derived from a small number of grab samples, the precision of this data could be rather low for a given site. However, when aggregated across the temporal and spatial extent of Ohio EPA database we expect that relationships between taxa relative abundance and maximum summer temperatures should be much more representative of taxa sensitivities. Figure 3 represents plots of WSVs based on maximum temperatures (°C) from grab samples at sites with macroinvertebrate taxa collected from artificial substrates in headwater and wadeable streams. The WSVs for maximum temperature generally track with the "general" tolerance categories assigned by Ohio EPA for each taxon for both headwater (Figure 3, upper right) and wadeable streams (Figure 3, lower right). A similar pattern was observed for fish species (Appendix 2). WSVs for temperature can be confounded with WSVs for other stressors, particularly habitat. However, the extremes of these distributions can be useful for identifying possible indicator taxa for future applications.

It was interesting to note that selected Chironomidae taxa occurred at both extremes of the WSV for temperature. For example *Paratanytarsus n.sp 1* had the lowest WSV for temperature at wadeable sites and *Parachironomus "hirtalatus"* and *Tanypus neopunctipennis* had among the highest WSVs (Figure 3, lower left). Additional analysis using environmental traits could help in determining the rare taxa that could exhibit some sensitive traits, but which may be too rare by themselves to serve as useful indicators.

Hydro-QHEI

We generated WSVs for Hydro-QHEI variables separately for headwater and wadeable streams for both fish and macroinvertebrates. We plotted several examples of the WSVs for these variables vs. the simple means for these same variables (Figure 4) in order to reveal the distributions of tolerant and sensitive species along this gradient as we did for temperature. Fish and macroinvertebrate WSVs for Hydro-QHEI and its subcomponents tracked relatively closely to the Ohio EPA tolerance designations for macroinvertebrate taxa and fish species (Appendix 2, Figure 4). Outlier points and variability are often associated with small sample sizes for a given species at a given stream size. Intolerant species are frequently rarer than "sensitive" species, especially so for fish, and as such may exhibit more variation than "sensitive" species where sample sizes are typically larger. As expected, tolerant species generally have wider sensitivity ranges.

Although QHEI is a visual habitat tool, recent analyses of variation from sites with multiple QHEI values using signal/noise ratio analyses indicate the index is precise and the subcomponents are moderately precise to precise (Miltner et al. 2009 Draft; Rankin et al., in preparation). We chose Hydro-QHEI subcomponents that are expected to change in response to flow alterations. For example the presence of fast current or the presence of eddies is a characteristic of permanent summer base flows (QHEI assessments are generally conducted during summer-fall low flow periods). Habitat attributes related to depth (i.e., deep pool and deep runs) are also associated with permanent base flows. Thus the Hydro-

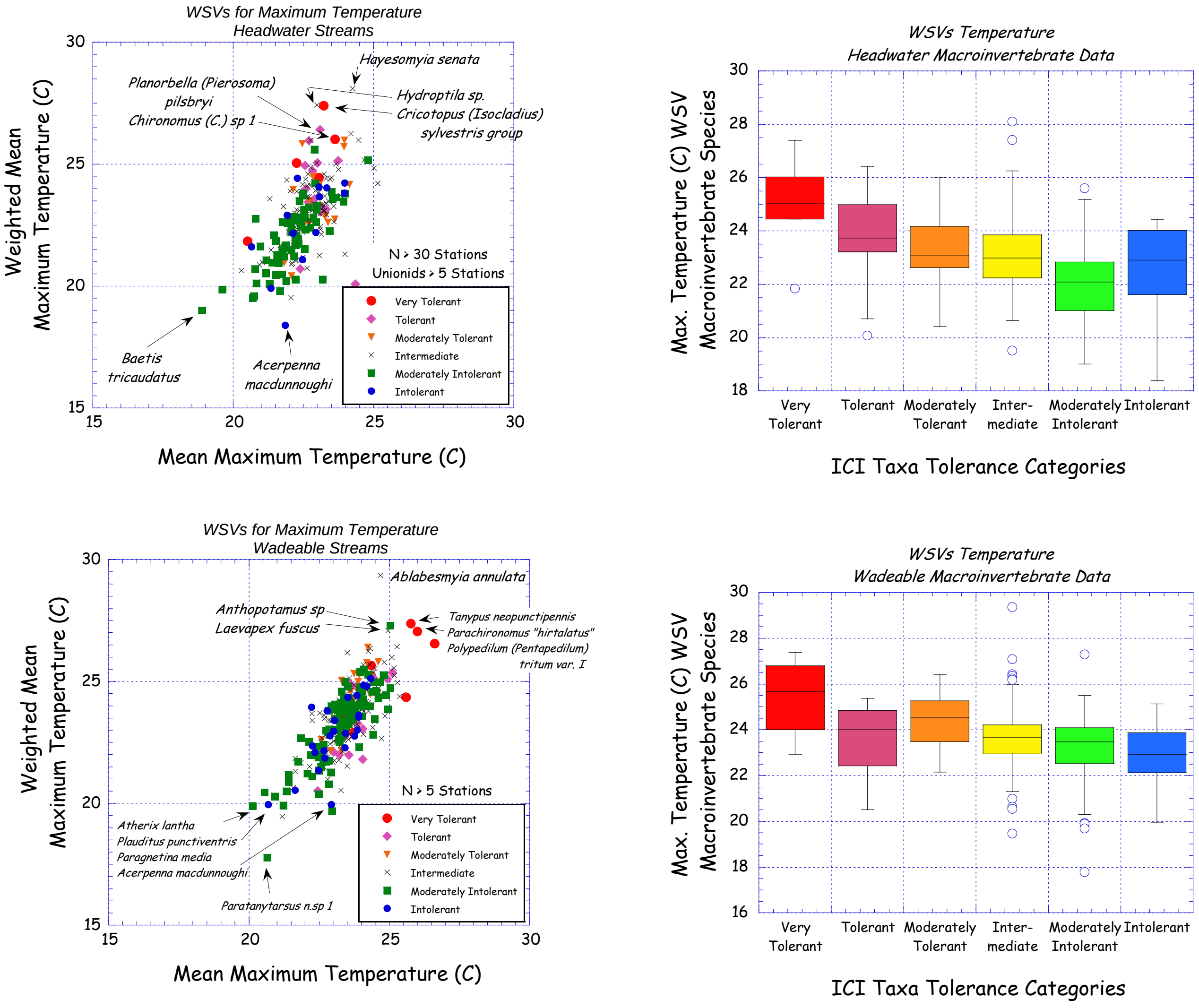


Figure 2. Plots of macroinvertebrate taxa maximum temperature WSV values vs. mean maximum values for taxa for headwater streams (upper left) and wadeable streams (lower left) and box and whisker plots of WSVs for maximum temperatures by Ohio EPA macroinvertebrate tolerance values (derived for the ICI) for headwater streams (upper right) and wadeable streams (lower right). Data for taxa represents data collected from artificial substrates where at least five samples were represented for each stream size category.

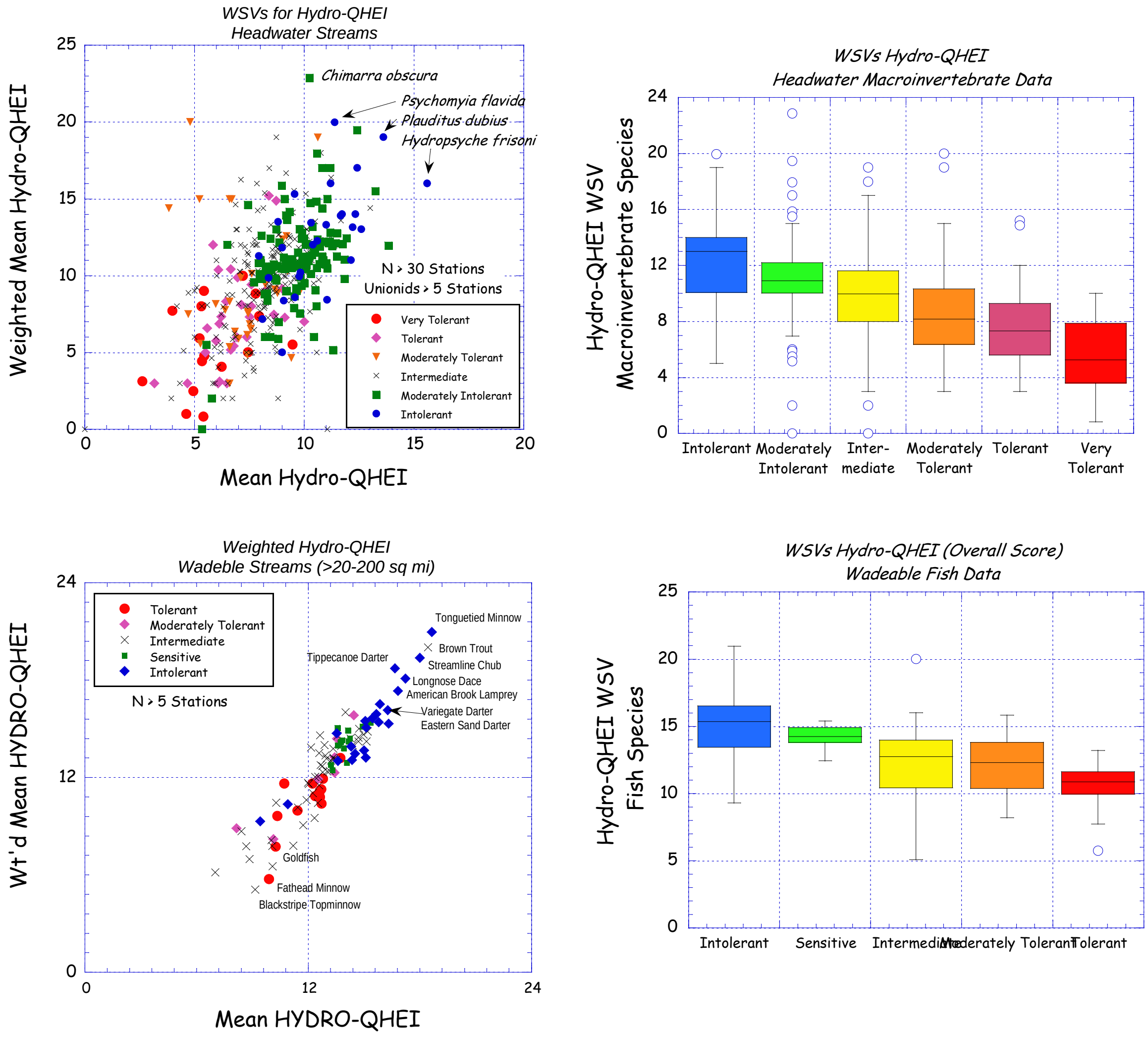


Figure 3. Scatter plots of taxa/species Hydro-QHEI WSV values vs. mean Hydro-QHEI values for macroinvertebrates taxa for headwater streams (upper left) and for species in wadeable streams (lower left) and box and whisker plots of macroinvertebrate (upper right) and fish (lower right) WSVs for Hydro-QHEI for these waters. Data from Ohio EPA.

QHEI is expected to reflect a gradient of base flow stability, one of the attributes that would be expected to change with changes in precipitation patterns as a result of climate change. Sensitive fish species and macroinvertebrate taxa were positively correlated with the Hydro-QHEI, thus it promises to be a useful tool for indicating hydrological changes that may be associated with climate change. These data are commonly collected by states throughout the Midwestern U.S.

Species Distribution by Stream Size

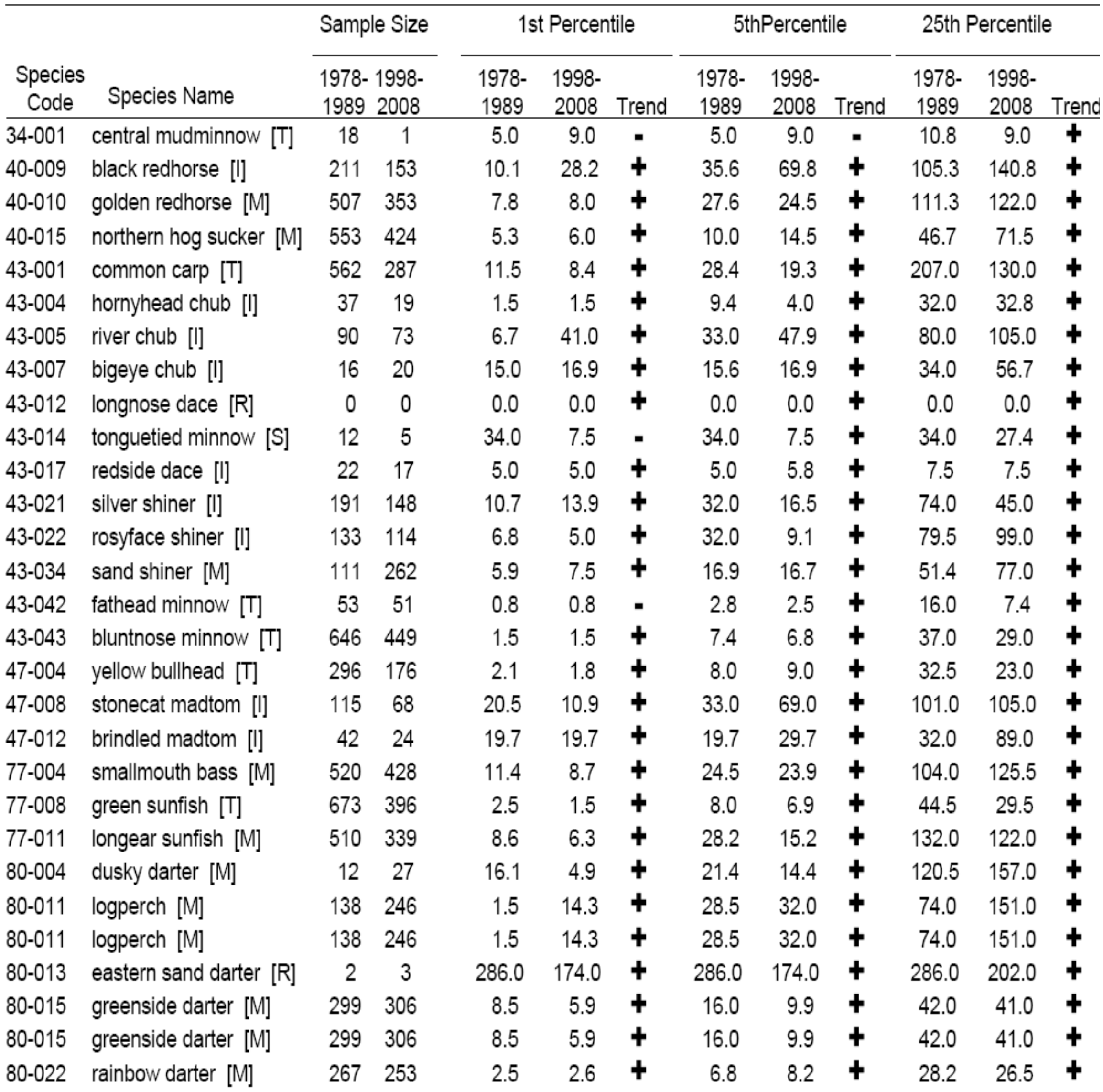
The identification of certain intolerant fish species in headwater streams at the “sensitive” end of the Hydro-QHEI gradient suggests that the distribution of these species at the tails of their preferred stream size range may reflect the degree of base flow. Fish species such as streamline chub, variegate darter, river chub and stonecat madtom (all with high Hydro-QHEI WSVs) are generally found in larger wadeable streams and their presence in headwater streams is associated with high Hydro-QHEI scores that indicate more stable flow regimes. Year-to-year or long term trends of these species in headwater streams could represent a response to climate-induced hydrologic changes. Thus we suggest that this could be an opportunity to explore whether the stream size "tails" of sensitivity distributions shift with hydrological change.

The Ohio database does contain a stream-size bias because headwater streams were less frequently sampled in the 1980s than in the 1990s and 2000s. With the knowledge of this bias as a test of the ability to detect species distribution changes at the edge of their distribution we divided the dataset into three time periods and examined whether a suite of sensitive species distributions along stream size was apparent through time. We recognized that the distribution of sites was different between these periods and we wanted to test whether it would be evident in low percentiles (1st, 5th, and 25th) for species distributions across all sites in Ohio. The results of this initial test showed that some bias between time periods exists for species distributions where nearly all selected sensitive species had distributions that extended further into small streams during the later (1998-2008) compared to the earliest (1978-1989) sampling periods (Table 8). In this table species with a + "increased" their distribution in small streams sampled in the most recent years (Ohio EPA 2002).

We then restricted this analysis to sites that had only been sampled in all three sampling periods so that the resulting distributions were not an artifact of stream size bias. The distribution of each species was then examined along a stream size gradient as measured by the same low percentiles (1st, 5th and 25th) (Table 8). There is still a possible bias in this initial analysis because some of these sites that were sampled across all three periods may have been sampled more frequently during some periods which could increase the probability of capture. However, as an initial exploratory analysis we were interested in whether any obvious trends were apparent.

The results (Table 9) do not indicate evidence of the same patterns similar to what was evident in Table 8 that were attributable to the sampling frequency among small streams. This analysis assumes, however, that some strong long-term shifts would have occurred during these time periods that would affect the tails of stream size distributions more than inter-annual flow variation. A more sensitive analysis would control or consider year-to-year variability in flow or temperature within each time periods that may confound the current analysis. We suggest that these distributional shifts could be a fruitful path for analysis when annual variation and regional variation in flows, which can be extracted from USGS flow data using IHA flow indicators, are incorporated into the analyses. The initial analyses conducted herein were done establish a basis for more detailed analyses.

Table 8. Analysis of frequency of species collections by stream size as measure by 1st, 5th and 25th percentiles of drainage area at sites with these species collected.



		Sample Size		1st Percentile			5thPercentile			25th Percentile		
Species Code	Species Name	1978-1989	1998-2008	1978-1989	1998-2008	Trend	1978-1989	1998-2008	Trend	1978-1989	1998-2008	Trend
34-001	central mudminnow [T]	18	1	5.0	9.0	-	5.0	9.0	-	10.8	9.0	+
40-009	black redhorse [I]	211	153	10.1	28.2	+	35.6	69.8	+	105.3	140.8	+
40-010	golden redhorse [M]	507	353	7.8	8.0	+	27.6	24.5	+	111.3	122.0	+
40-015	northern hog sucker [M]	553	424	5.3	6.0	+	10.0	14.5	+	46.7	71.5	+
43-001	common carp [T]	562	287	11.5	8.4	+	28.4	19.3	+	207.0	130.0	+
43-004	hornyhead chub [I]	37	19	1.5	1.5	+	9.4	4.0	+	32.0	32.8	+
43-005	river chub [I]	90	73	6.7	41.0	+	33.0	47.9	+	80.0	105.0	+
43-007	bigeye chub [I]	16	20	15.0	16.9	+	15.6	16.9	+	34.0	56.7	+
43-012	longnose dace [R]	0	0	0.0	0.0	+	0.0	0.0	+	0.0	0.0	+
43-014	tonguetied minnow [S]	12	5	34.0	7.5	-	34.0	7.5	+	34.0	27.4	+
43-017	redside dace [I]	22	17	5.0	5.0	+	5.0	5.8	+	7.5	7.5	+
43-021	silver shiner [I]	191	148	10.7	13.9	+	32.0	16.5	+	74.0	45.0	+
43-022	rosyface shiner [I]	133	114	6.8	5.0	+	32.0	9.1	+	79.5	99.0	+
43-034	sand shiner [M]	111	262	5.9	7.5	+	16.9	16.7	+	51.4	77.0	+
43-042	fathead minnow [T]	53	51	0.8	0.8	-	2.8	2.5	+	16.0	7.4	+
43-043	bluntnose minnow [T]	646	449	1.5	1.5	+	7.4	6.8	+	37.0	29.0	+
47-004	yellow bullhead [T]	296	176	2.1	1.8	+	8.0	9.0	+	32.5	23.0	+
47-008	stonecat madtom [I]	115	68	20.5	10.9	+	33.0	69.0	+	101.0	105.0	+
47-012	brindled madtom [I]	42	24	19.7	19.7	+	19.7	29.7	+	32.0	89.0	+
77-004	smallmouth bass [M]	520	428	11.4	8.7	+	24.5	23.9	+	104.0	125.5	+
77-008	green sunfish [T]	673	396	2.5	1.5	+	8.0	6.9	+	44.5	29.5	+
77-011	longear sunfish [M]	510	339	8.6	6.3	+	28.2	15.2	+	132.0	122.0	+
80-004	dusky darter [M]	12	27	16.1	4.9	+	21.4	14.4	+	120.5	157.0	+
80-011	logperch [M]	138	246	1.5	14.3	+	28.5	32.0	+	74.0	151.0	+
80-011	logperch [M]	138	246	1.5	14.3	+	28.5	32.0	+	74.0	151.0	+
80-013	eastern sand darter [R]	2	3	286.0	174.0	+	286.0	174.0	+	286.0	202.0	+
80-015	greenside darter [M]	299	306	8.5	5.9	+	16.0	9.9	+	42.0	41.0	+
80-015	greenside darter [M]	299	306	8.5	5.9	+	16.0	9.9	+	42.0	41.0	+
80-022	rainbow darter [M]	267	253	2.5	2.6	+	6.8	8.2	+	28.2	26.5	+

Table 9. Analysis of frequency of species collections by stream size as measured by 1st, 5th and 25th percentiles of drainage area at sites with these species collected.

		Sample Size		1st Percentile			5thPercentile			25th Percentile		
Species Code	Species Name	1978-1989	1998-2008	1978-1989	1998-2008	Trend	1978-1989	1998-2008	Trend	1978-1989	1998-2008	Trend
01-006	least brook lamprey [ ]	19	16	4.9	4.9	-	4.9	4.9	-	16.3	9.6	+
34-001	central mudminnow [T]	18	1	5.0	9.0	-	5.0	9.0	-	10.8	9.0	+
40-009	black redhorse [I]	211	153	10.1	28.2	-	35.6	69.8	-	105.3	140.8	-
40-010	golden redhorse [M]	507	353	7.8	8.0	-	27.6	24.5	+	111.3	122.0	-
40-015	northern hog sucker [M]	553	424	5.3	6.0	-	10.0	14.5	-	46.7	71.5	-
43-001	common carp [T]	562	287	11.5	8.4	+	28.4	19.3	+	207.0	130.0	+
43-004	hornyhead chub [I]	37	19	1.5	1.5	-	9.4	4.0	+	32.0	32.8	-
43-005	river chub [I]	90	73	6.7	41.0	-	33.0	47.9	-	80.0	105.0	-
43-007	bigeye chub [I]	16	20	15.0	16.9	-	15.6	16.9	-	34.0	56.7	-
43-012	longnose dace [R]	0	0	0.0	0.0	-	0.0	0.0	-	0.0	0.0	-
43-014	tonguetied minnow [S]	12	5	34.0	7.5	+	34.0	7.5	+	34.0	27.4	+
43-017	redside dace [I]	22	17	5.0	5.0	-	5.0	5.8	-	7.5	7.5	-
43-021	silver shiner [I]	191	148	10.7	13.9	-	32.0	16.5	+	74.0	45.0	+
43-022	rosyface shiner [I]	133	114	6.8	5.0	+	32.0	9.1	+	79.5	99.0	-
43-034	sand shiner [M]	111	262	5.9	7.5	-	16.9	16.7	+	51.4	77.0	-
43-042	fathead minnow [T]	53	51	0.8	0.8	-	2.8	2.5	+	16.0	7.4	+
43-043	bluntnose minnow [T]	646	449	1.5	1.5	-	7.4	6.8	+	37.0	29.0	+
47-004	yellow bullhead [T]	296	176	2.1	1.8	+	8.0	9.0	-	32.5	23.0	+
47-008	stonecat madtom [I]	115	68	20.5	10.9	+	33.0	69.0	-	101.0	105.0	-
47-012	brindled madtom [I]	42	24	19.7	19.7	-	19.7	29.7	-	32.0	89.0	-
54-002	blackstripe topminnow [	74	36	2.6	1.5	+	10.3	2.6	+	32.0	25.0	+
77-004	smallmouth bass [M]	520	428	11.4	8.7	+	24.5	23.9	+	104.0	125.5	-
77-008	green sunfish [T]	673	396	2.5	1.5	+	8.0	6.9	+	44.5	29.5	+
77-011	longear sunfish [M]	510	339	8.6	6.3	+	28.2	15.2	+	132.0	122.0	+
80-004	dusky darter [M]	12	27	16.1	4.9	+	21.4	14.4	+	120.5	157.0	-
80-011	logperch [M]	138	246	1.5	14.3	-	28.5	32.0	-	74.0	151.0	-
80-013	eastern sand darter [R]	2	3	286.0	174.0	+	286.0	174.0	+	286.0	202.0	+
80-015	greenside darter [M]	299	306	8.5	5.9	+	16.0	9.9	+	42.0	41.0	+
80-022	rainbow darter [M]	267	253	2.5	2.6	-	6.8	8.2	-	28.2	26.5	+
90-002	mottled sculpin [ ]	107	137	1.5	1.5	-	2.5	4.9	-	9.6	16.7	-
95-001	brook stickleback [ ]	17	10	7.4	7.4	-	8.6	7.4	+	21.0	8.0	+

Discussion and Recommendations

A goal of this initial exploration was to examine whether the Ohio reference dataset is suitable for detecting potential and expected effects of global climate change through temperature or hydrological alterations. Ohio is species/taxa rich with a strong gradient and diversity of "general" tolerance from highly intolerant to highly tolerant to chemical, physical, and habitat stressors. WSVs for temperature and Hydro-QHEI variables indicate that the sensitivity to these parameters is correlated with the "general" sensitivity rankings of these taxa and species assigned by Ohio EPA. The species that make up the extremes of these relationships are the principal candidate species for more detailed trend analyses. An example is the tonguetied minnow *(Exoglossum laurae)* which is an occupant of cool, high base flow, headwater and wadeable streams in the Mad River subbasin of west central Ohio. Many small streams in the Mad River subbasin are characterized by high base flows resulting from groundwater inputs as a result of the unique surficial geology. Another locally distributed cool water species would be longnose dace *(Rhinichthys cataractae)* that has a localized distribution in the small streams of eastern Ohio. Other useful fish indicators would be those species that require stable flow and temperature conditions and which can extend their ranges into headwater-sized streams when conditions are right (constant flow, cool water). Candidate species include banded darter *(Etheostoma zonale),* river chub *(Nocomis micropogon),* and carmine shiner *(Notropis rubellus*; see Appendix 2). The ranges of many macroinvertebrate taxa are less well known than fish, but taxa richness remains high into very small headwater streams making these equally good candidates for trend analyses based on yearly or periodic flow changes.

We suggest that the greatest immediate influence of climate change on aquatic assemblages will be most detectable in headwaters streams. Both fish and macroinvertebrate assemblages are sufficiently species and taxa rich in such streams with macroinvertebrates extending into the smallest headwater streams (<1 mi.^{2}). Although these effects may well propagate into larger water bodies over time, the shear volume of flow in larger streams and rivers could buffer the detection of changes in both temperature and hydrological regime which would not be a suitable "early warning" signal. In addition, larger streams and rivers are more likely to be influenced by a more complex suite of non-thermal and hydrological stressors that are both decreasing (e.g., point source impacts) and potentially increasing (e.g., suburban and urban stormwater, EDCs) in occurrence. Although such landscape changes can and do occur in small watersheds, such changes can be more readily accounted for in the data analyses. The strength of the Ohio dataset is in the extent of the temporal and spatial coverage and the diversity of stressor impacts and gradients. One shortcoming is that only a few selected river sites and no headwater sites are sampled *every year* to provide a long-term record for single streams to reveal trends at a representative scale. Hence monitoring sentinel headwater streams that are representative of a gradient of known and emerging impacts would be a useful adjunct to Ohio's robust statewide database.

Two Types of Headwater Streams

Ohio identifies two sizes of headwater streams; headwater streams (HW) and primary headwater streams (PHW). HWs are streams <20 mi.^{2} in size and have been sampled using Ohio EPA (1989) standardized fish, macroinvertebrate, and habitat methods since the late 1970s. While some stream sites <1 mi.^{2} have been sampled with these methods, most data is from sites of >1-20 mi.^{2} Monitoring methods have recently been developed for PHW streams (Ohio EPA 2002a, b, c, d, 2003) which are generally less than 1 mi.^{2}, although the monitoring technique has been applied to streams up to 3 mi.^{2} The PHW assessment substitutes salamanders for fish along with macroinvertebrates. This assemblage has been used elsewhere as indicators of climate change. The long term data set we examine here was focused on wadeable and HW streams; data on PHW streams has been collected only since the late 1990s and in a less extensive manner hence it was not included in our initial analyses.

We recommend that future climate change monitoring be focused on PHW streams and smaller HW streams (<10 mi.^{2}). Ohio methodologies for both types of streams are sound and there is an existing database that can provide useful data at broad spatial scales for trend assessment. U.S. EPA has also developed sampling methodologies (Fritz et al. 2006). We suggest that an ecoregional network of sentinel sites be established where more frequent and detailed sampling would be conducted annually to include flow, temperature, geomorphology, habitat, water quality, and biological indicators (macroinvertebrates, fish), and amphibians at a longitudinal scale and density sufficient to identify changes in taxa/species distributions within stream size strata. Detailed collection of flow data in Ohio and most states is generally located on larger waters and the results are extended to smaller waters via extrapolation. Given the dynamic nature of small streams detailed flow data from a cross section of headwater streams would be desirable. In addition to the 'traditional' biological indicators described above, Ohio researchers have also begun to build datasets for algae and periphyton (e.g., Verb and Vis 2000, Verb et al. 2006) and for protists (??need ref??). The usefulness of these assemblage groups would also be useful for providing a more mechanistic understanding of how ecosystems are being altered by climate change related to both temperature and flow.

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Appendix 1: Accounting of Macroinvertebrate Taxa Appearances in Ohio Rivers and Streams

Appendix 2: Weighted Stressor Values for Fish Species and Macroinvertebrate Taxa in the Ohio Streams and Rivers Database