An Index of Biotic Integrity for Macroinvertebrates and Salamanders in Primary Headwater Habitat Streams in Ohio

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By

Edward L. Moore, Jr.

Graduate Program in Natural Resources

The Ohio State University

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Master's Examination Committee:

Dr. Robert Gates, Advisor

Dr. Lance Williams

Dr. Charles Goebel

Dr. Robert D. Davic

Dr. Richard Moore

ABSTRACT

The use of multimetric indices to assess aquatic communities is well established in Ohio. The fish Index of Biotic Integrity (IBI) and the Invertebrate Community Index are robust measures of aquatic community condition that have been used by the Ohio Environmental Agency (OEPA) for many years. These indices provide a definitive numeric assessment of the stream biotic communities to judge against established biocriteria in state water quality standards. However, neither of these assessment tools can be applied to the smallest headwater streams of watersheds. At the scale of the primary headwater habitat stream (PHWH) defined by OEPA as having shallow pools and a drainage area less than 2.56 km^2, the ability to collect a quantitative sample using OEPA macroinvertebrate quantitative sampling methods was not successful. In addition, it was found that electrofishing methods to sample the fish community was not appropriate for primary headwater streams where fish are rare, or more often completely absent.

The Ohio EPA does not allow an assessment of attainment of stream quality unless a fish IBI score or an ICI is documented at that site. A qualitative narrative assessment of the macroinvertebrate community can be used to

designate a stream use (e.g., coldwater habitat, warmwater habitat) but not an assessment of whether the stream community is attaining or meeting that designated use. Salamanders have been used by the Ohio EPA since 2002 to help determine PHWH stream classes (I, II, III) with the Class III PHWH having the highest quality biotic integrity and most ecologically sensitive taxa. Class III PHWH streams are dominated by cold water adapted macroinvertebrate taxa and by various salamander species, which ecologically replace the predatory functional role of fish.

There is no recognized assessment tool at present using either macroinvertebrates or salamanders to determine attainment of Clean Water Act goals for primary headwater streams in Ohio (<2.56 km^2). The goal and objective of this study was to develop various indices of biotic integrity to be used as biomonitoring assessment tools for Class III primary headwater habitat streams. Macroinvertebrate assemblage data and salamander community data were investigated to score and evaluate whether known Class III PHWH streams were meeting performance standards as documented at least impacted PHWH watershed sites from this study.

PHWH sample sites were selected in central, north-central, and northeast Ohio that covered a range of human disturbance conditions (high quality reference sites to poor condition sites). Site and community quality differences developed a better understanding of the species-environment relationship that would define and establish responsiveness and suitability of possible metrics in the ICI development process. Quantitative sampling methods were compared (Surber, artificial leaf pack sample, and USEPA bucket sampling methods) for variability and suitability in sampling PHWH streams. The bucket sample method was selected as most appropriate for PHWH invertebrate stream sampling. Qualitative sampling of stream reach microhabitats (with presence/absence data) following OEPA protocols supplemented the quantitative samples. Direct gradient ordination (redundancy analysis - RDA) of the macroinvertebrate data and measured environmental variables was conducted to discern invertebrate taxa-environment relationships. Potential invertebrate metrics were included as passive species variables in the ordination so that they did not affect the position of the invertebrate taxa. Sensitive invertebrate taxa and metrics grouped around positively correlated environmental vectors in the RDA triplot, such as riparian width, forest cover, low embeddedness, maximum pool depth, and substrate quality. Reference sample sites were located in the positively correlated quadrants also with taxa nearby related to the respective sites and the positive environmental vectors. Facultative taxa were centered in the RDA analysis triplot near the moderate quality range of condition sites. Poor quality sites, tolerant invertebrate taxa, and negatively correlated environmental vectors, such as total suspended solids, percent silt and muck, and temperature, were grouped in negative quadrant of triplot. A distance matrix analysis (which measures the relatedness of data spatially) grouped possible invertebrate metrics into clusters based on their similarity. Invertebrate metrics for the PHWH Invertebrate Community Index (ICI) were selected from each cluster group after comparisons of utility (amount of information), redundancy, scope and the ability to reflect a wide range of conditions while distinguishing reference sites from disturbed sites. These comparisons were from statistical and empirical analyses of quantitative and qualitative sample data collected at Class III PHWH sample sites. The 14 selected invertebrate metrics were standardized by scoring continuously from 0 to 1 using a curvilinear equation developed from the relationship of the reference data and the range of condition sites. For each invertebrate metric, the minimum reference value scoring a metric score of 1 was determined along with the value where a 0 was scored. An invertebrate metric equation was developed for each metric with at least those points (or more) similar to the shape of the frequency distribution curve and then scaled to produce an ICI of 0 to 100. The developed PHWH ICI scored consistently and documented range of quality conditions among sample sites. All PHWH reference sites scored ≥ 70% to 100%. Range of condition sites scored from < 10% to under 60%. Based on sample site scoring, the PHWH ICI biomonitoring criterion met PHWH Class III macroinvertebrate community performance expectations at scores ≥ 70%. Associated narrative quality evaluations meeting Class III PHWH community performance expectations were designated as: 70% to < 80% (good); 80% to < 90% (very good); and ≥ 90% (exceptional quality). PHWH ICI scores under 70% did not meet macroinvertebrate community quality expectations and were categorized as: 40% to ≤ 70% (fair quality); 30% to ≤ 40% (poor); and < 30% (very poor quality). These narrative quality categories were similar to OEPA narrative quality categories used in qualitative narrative assessments.

A Salamander Community Quality Index was developed from five different possible diversity indices of varying complexity with combined data from the 10 meter Visual Encounter Survey (VES) and incidental collections from the macroinvertebrate qualitative and quantitative sampling methods. The Visual Encounter Survey (VES) was determined to be the primary sampling method with supplemental incidental salamander collection data from the PHWH macroinvertebrate samples added to counts to get cumulative scores. Five stream-obligate salamander species were collected at 19 of 21 (90.5%) PHWH sample sites. Reference sites contained 3-5 salamander species at 7 of 10 sites. Positive common associations of species diversity were wide riparian corridors (range of 235-750 m), low percent silt and muck (range of 0-5%), and a mean forest cover of 56.4%. Conversely, low salamander diversity was influenced by increased percentages of cropland, silt and muck, and open canopy. Low riparian widths (0 and 2.25 meters) were measured at PHWH sites where no salamanders were collected. The Salamander Community Quality Index responded to environmental disturbances, and a wide range of quality was expressed between reference sites and the range of condition sites. The Salamander Community Quality Index (SCQI) was selected from five possible indices (index 4 with modifications) by comparisons and practical differences in scoring and data documentation for interpreting scoring. Index 4 had enough detail to document multiple year classes for site quality differentiation, yet index 4 was not so complex that it was not reproducible by herpetology non-experts. Sites that scored a Salamander Community Quality Index $\geq$ 20 (7 of 21 sites)

contained good salamander diversity and had good to exceptional quality associated habitat (HHEI scores of 62-96). The Salamander Community Quality Index biomonitoring criterion, based on sample site scoring, met PHWH Class III salamander community performance expectations at scores $\geq$ 20 (of 50 possible points) or 40%.

Both the PHWH ICI Salamander Community Quality Index responded to environmental disturbances, and a wide range of quality was expressed between reference sites and the range of condition sites. A strong association was documented in a correlation analysis between the PHWH ICI and the Salamander CQI (r = 0.723; $P < 0.010$, 20 df). Consequently, the two Indices, the PHWH ICI and the Salamander Community Quality Index, were combined to form the Primary Headwater Community Quality Index (PHWH CQI). The use of both invertebrate and vertebrate response indicators to determine the biotic integrity of primary headwater streams is consistent with the OEPA approach for larger streams where both the fish IBI and macroinvertebrate ICI are utilized. The Primary Headwater Community Quality Index (consisting of the independent PHWH ICI and the Salamander CQI) can be applied to determine use attainment, preservation, mitigation, restorability, long-term land use development for watershed planning, and for establishing biocriteria for primary headwater streams wherever Class III type biological communities are documented to be present (with some localized limitations).

DEDICATION

This thesis is dedicated to my wife, Patricia Moore, and family. Without your support and patience and God's grace, I would not have made it. I thank you for your encouragement and for those times when you picked up the slack and filled in the gap. Tric, thanks for putting up with everything without me. I know I could not have done it without you and am so full of gratitude. I love you.

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VITA

October 1, 1961…………………………….Born – North Kansas City, Missouri

August 1979 to May 1981………………...Centre College of Kentucky
Danville, Kentucky

May 1983…………………………………...B.S. Wildlife & Conservation Mgt. – Aquatic Option,
University of Wyoming
Laramie, Wyoming

Sept. 1981 to Sept. 1985……………….Laboratory Research Associate
Dept. of Zoology
University of Wyoming
Laramie, Wyoming

Sept. 1985 to June 1988………………..Laboratory Research Associate
Battelle Memorial Institute
Columbus, Ohio

June 1988 to December 1995………….Ohio EPA, Bioassay Section
Div. of Environmental Services
Columbus, Ohio

December 1995 to current..…………….Ohio EPA
Monitoring & Assessment Section
Division of Surface Water
Columbus, Ohio

FIELDS OF STUDY

Major Field: Natural Resources
Aquatic Ecology
Fisheries Biology

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Ephemeroptera/Plecoptera/Trichoptera	EPT
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Index of Biotic Integrity	IBI
Invertebrate Community Index	ICI
Limited Resource Water	LRW
National Pollution Discharge Elimination System	NPDES
Ohio Environmental Protection Agency	OEPA
Primary Headwater Habitat	PHWH
Primary Headwater Habitat Invertebrate Community Index	PHWH ICI
Primary Headwater Habitat Community Quality Index	PHWH CQI
Salamander Community Quality Index	SCQI
Total Maximum Daily Load	TMDL
United States Environmental Protection Agency	USEPA
Visual Encounter Survey	VES
Warmwater Habitat	WWH

CHAPTER 1

PROJECT OVERVIEW

Literature Review

Ecological Concept of Biotic Integrity

The historical rationale for water quality monitoring and assessment has been developed on the need to identify and restore damaged waters that were impaired by various toxic chemical and physical alterations by direct human influences, and nonpoint source inputs that affect the biological communities. One such assessment tool is the Index of Biotic Integrity (IBI), which was developed first for fish (Gammon et al.. 1979, Karr 1981) and has been widely used in the United States and worldwide for a variety of indicator groups including benthic macroinvertebrates, algae, and plankton (Karr and Yoder 2004).

Biotic integrity in stream ecology has been defined “as the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region” (Karr and Dudley 1981). Water quality evaluation originally focused on chemical parameter concentrations and toxicity, but it has been widely recognized that multiple factors affect and contribute to the degradation and decline of surface water quality and biotic integrity (e.g., loss of habitat structure) (Karr and Dudley 1981, Schaeffer et al. 1985, Karr et al. 1986).

Anthropogenic or human disturbance activities continue to play an important role in disrupting stream ecosystems in Ohio, the Midwest, and worldwide (Resh et. al. 1988, Yoder and Rankin 1998). Some causative factors include modification or destruction of riparian and aquatic habitats, channel sedimentation, natural flow alteration, and losses of overhanging canopy that would allow increased temperatures and excessive algal production changing the aquatic invertebrate community structure (Karr et al. 1986, Yoder and Rankin 1998). Major human disturbances affecting stream ecosystems in Ohio include: (1) logging and land clearing for agriculture or animal husbandry; (2) draining wetlands; (3) channelizing small and large streams; (4) tile inputs for drainage; (5) mining; (6) industrialization; (7) dams; and (8) urbanization (Howe 1997). The main causes of impairment include: altered physical / riparian habitat (ditching or channelization or loss of riparian habitat); altered flows (possibly drainage tiling);

increased sedimentation/siltation; organic enrichment; nutrients, and pathogens (Karr and Yoder 2004).

Numerical biocriteria, based on the fish IBI and the Invertebrate Community Index (ICI), and multiple aquatic life designated uses (e.g., Warmwater, Coldwater, and Limited Warmwater Habitats) have been encoded in Ohio law statutes since 1990. These aquatic life use and monitoring statutes have profoundly influenced all aspects of water quality management (e.g., strategic planning, water quality standards, nonpoint source assessment, monitoring and problem discovery) in ecological systems (Yoder and Rankin 1998).

There are five generally accepted classes of biotic and abiotic factors that affect aquatic biota: chemical variables, flow regime, biotic factors, energy sources, and habitat structure (Figure 1.1) (Yoder and Rankin 1998). These factors respond to stressor inputs that cause changes in biological communities and the integrity of water resources. Multimetric indices, like the Ohio Environmental Protection Agency fish IBI and the ICI for macroinvertebrates (Deshon 1995) were developed to portray the status of community health (biological integrity) through any changes in fish or benthic communities that could be affected by various environmental variables at different scales and processes, thus changing a particular portion of the community or its structure (Williams et al. 2003).

These indices were developed to respond to various impairments from the range of human disturbance (Yoder and Rankin 1998). Some earlier indices were developed initially for organic stream pollution (Hilsenhoff 1997, 1988, Jones et al. 2002). Index scores scaled and compared against the standards of reference conditions can account for natural variability among equally healthy

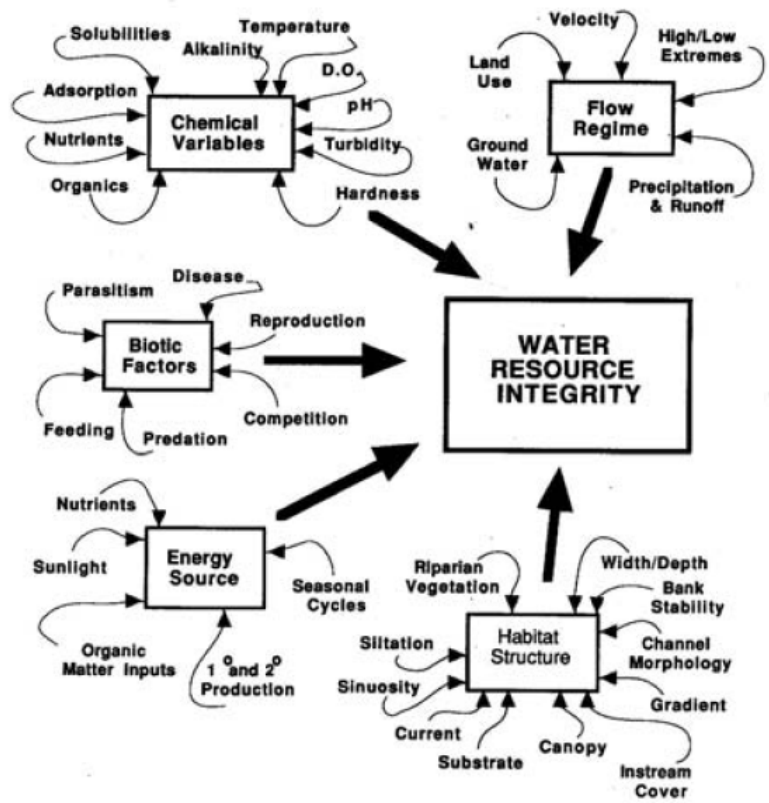

Figure 1.1. The five principle factors of surface water resource integrity with some of the key physical, chemical, and biological components that affect and influence water and biological community quality (Yoder and Rankin 1998 modified from Karr et al. 1986).

sites. The assumption is that biological communities at test sites will be similar to reference sites with similar habitat conditions in the absence of human disturbance (Jones et al. 2002).

Biotic Integrity of Headwater Habitats

Biological quality and integrity of larger streams have been linked directly to its headwater stream quality in subwatersheds. Headwater streams make up 80% of the national stream network (Meyer et. al. 2003) and are critical for controlling water flow, nutrients, and organic material downstream. For example, model-based research stated that 64% of inorganic nitrogen inputs are retained or transformed within 915 meters of entry into stream (Meyer et al. 2003). Land development has caused many headwater streams to be filled, piped, channelized, degraded and/or destroyed. Many headwater streams have diminished capacity to absorb, retain, control, and /or recycle stormwater, nutrients, sediments, and organic matter. Headwater stream destruction has allowed continued nutrient and sediment transport downstream, increasing eutrophication in larger streams and rivers (Meyer et al. 2003). Mining, for instance, has filled over 1,440 river km of headwater stream networks in West Virginia and surrounding Appalachian states (Meyer et al. 2003).

The Federal Clean Water Act’s (Section 101a) stated objective to “maintain the biological integrity of the Nation’s waters” has caused more attention to be placed on protecting headwater streams than in the past.

Biological criteria for fish and/or macroinvertebrates as biological indicators have been developed in Ohio, Maine, and Florida (Barbour et al. 1996). In an attempt to monitor smaller streams, the Ohio fish IBI and ICI for macroinvertebrates has been used at stream drainages as small as 2.56 km^2 where the stream reach had the proper depth and minimum flows required for a valid sample using Hester Dende colonizers (DeShon 1995). Smaller streams less than 12.95 km^2 were usually only sampled qualitatively (presence / absence data) with a field assessment and a qualitative narrative assessment after taxa identification (DeShon et al. 1980).

Because of the USEPA requires states to identify and mitigate all impaired waters under the Total Maximum Daily Load (TMDL) mandate – a process to improve water quality – more emphasis has been placed on biological monitoring and assessment (Karr and Yoder 2004). Hence more systematic sampling at smaller drainage areas has been the trend throughout the subwatersheds of river basins to better evaluate watershed health (OEPA 2002). As headwater stream sampling increased by 50%, the documented impairment of smaller Ohio stream reaches was due particularly to various nonpoint source agricultural inputs or habitat or flow alteration in rural, urban, and rapidly suburbanizing landscapes (Miltner, White, and Yoder 2003, Yoder and Rankin 1998). So the impetus for better assessment of the smallest headwater tributaries has increased, as the uppermost reaches of the river continuum have been impacted and bear the biggest brunt of impairment (Vannote et al. 1980 in Jones et al. 1995). There also was a recognized need for more detailed understanding of the invertebrate community – environment relationships, assessment, analysis and remediation among many concerned constituents (Meyer et al. 2003).

Ohio EPA Primary Headwater Habitat Streams

A classification system to define categories for Primary Headwater Habitat (PHWH) streams was developed by the Ohio EPA in 2002 (OEPA 2002a). The PHWH stream had been defined as "a channel with a well-defined bed-bank, having continuous or periodically flowing water, a drainage area of <2.56 km^2 and maximum pool depths of <40 cm during base flow conditions: (Ohio EPA 2002a,b,c,d). Three types of stream classes were recognized. The Class III PHWH has biological communities adapted to cool-cold water in summer months, perennial flow duration, and heterogeneous physical habitat. The Class II PHWH has biology mostly adapted to intermittent flow, warmer stream temperatures, and less habitat diversity. The Class I PHWH is ephemeral and has little potential to support a diverse community of aquatic life.

Prior to European-American settlement Ohio and the surrounding states had forested headwater streams that depended on allochthonous inputs (leaves, etc.). Agricultural land uses in Ohio and the Midwest changed those natural inputs in many situations (decreased riparian corridors) and increased primary productivity through nutrient inputs and/or loss of shading which also affected continuous flow in many situations (Watzin and McIntosh 1999; OEPA 1999; Karr et al. 1986). So changes to the landscape caused changes in quality or levels of biological community structure. However where least disturbed or mostly intact riparian subwatersheds were present, a clearly defined benthic community (salamanders and aquatic insects) was demonstrated.

The OEPA Class III stream was documented definitively three ways using biological communities: (1) by the presence of 3 or more cool-cold water adapted benthic macroinvertebrate taxa; (2) reproducing population of cold water fish as defined by Ohio EPA Cold Water designated aquatic life use; and (3) reproducing populations of salamander species with multi-year (> 12 months) larval periods (Ohio EPA 2002a). The PHWH Class III biotic community was distinct and of higher species richness and diversity than the PHWH Class II benthic community, as many PHWH Class II streams become mostly an intermittent condition annually at low flows (Ohio EPA 2002b). Resh et al. (1988) also noted that species communities in intermittent headwater streams were very different compared to perennial headwater streams fed by permanent springs or groundwater.

The Headwater Macroinvertebrate Field evaluation Index (HMFEI) which was used to help classify PHWH streams into Classes (I – III) documented community differences in the three PHWH stream classification types (OEPA 2002a-b). However, a quantitative evaluation tool to supplement the HMFEI and evaluate the PHWH macroinvertebrate community quality was needed. The HMFEI conservatively and adequately categorizes into stream classes but does not adequately illustrate the range of human disturbance condition with enough detail within classes. The HMFEI is not used by itself to assess success in meeting an expected level of community quality or restoration goal above its use to determine PHWH class levels.

Prior to this PHWH classification system being developed, the strategy in Ohio was to designate a headwater stream (drainage areas < 32.2 km^2) using existing aquatic life use categories to as small a drainage as possible where sufficient pool depth (> 40 cm), flow and gradient allowed for a permanent (all year) resident fish community. There was minimal protection as a Limited Resource Water designated stream for the stream reaches further upstream where the existing fish IBI and ICI sampling procedures did not apply. Since 2002, the PHWH classification system has been used to identify different types of headwater streams at a stream size threshold where pool depths and other functional features preclude permanent fish populations, and salamanders have begun to dominate the top predator position (Davic and Welsh 2004, Petranka 1998; OEPA 2002b).

A defined PHWH macroinvertebrate community has been known to inhabit the upper reaches in the stream network of watersheds (Vannote et al. in Jones et al. 1995). The least disturbed PHWH stream systems in Ohio and the Midwest were related to deciduous forests with good streamside riparian corridors – sufficient for rainfall to regenerate to groundwater, and limit or sequester nonpoint source (NPS) inputs like sediments, nutrients, pesticides, and pathogens (Barbour et al. 1992; Resh et al. 1988; Karr et al. 1986; Meyer et al. 2003). Macroinvertebrate taxa species richness and diversity at intact PHWH systems should be high and stable. At least disturbed PHWH sites taxa species richness or the number of Ephemeroptera / Plecoptera / Trichoptera (EPT) taxa or even rare or sensitive indicator species (like the caddisflies *Glossosoma sp*., most *Rhyacophila* sp., or *Dolophilodes sp*.) should be high. Conversely rare and sensitive species were or should be less prevalent or disappear in more disturbed patches (Riece 1985 in Resh et. al. 1988). As the patchiness in land use increases in headwater stream reaches this should affect stream biota quality and community quality persistence. The magnitude at which human disturbance impacts affect PHWH benthic communities depends on the protective nature of the riparian corridor environment still present. As data accumulates, a relationship between riparian corridor width or a minimum length of continuous intact riparian corridor and PHWH stream community quality might be the outcome of the development and use of a headwater quality index to assess effects, species-environment relationships, and restoration options.

Development of an Index of Biotic Integrity for Headwater Habitats

Many different methods have been previously used in stream sampling. Macroinvertebrates are sampled with through D-nets, surbers, substrate sample colonizers, bucket sampling and others methods such as a combination of hand-picking and D-frame net sweeps of five habitats) (Hilsenhoff 1987; OEPA 1987; DeShon 1995; Townsend and Scarsbrook 1997; Barbour et al. 1995; USEPA

2006, Chessman and McEvoy 1997). Sampling choice seemed to be based on condition of the natural stream habitat (i.e., like combination lotic and lentic Florida stream systems – Barbour et al. 1995) and the analysis method. Any multimetric index developed for PHWH streams must differentiate between reference conditions and changes in community quality/diversity from disturbances that seem plausible and appropriate (response and range of changes).

The multimetric index approach has been utilized by many investigators (OEPA 1987a,b, Barbour et al. 1992, 1996). Taxa richness, EPT taxa and the modified Family Hilsenhoff Biotic Index were among others recommended from the review of the Rapid Bioassessment Protocol Benthic Community Assessment (Barbour et al. 1992; Plafkin et al. 1989). The rigor of taxonomic identification needed also to be considered. Hilsenhoff (1988) warned against using just the Family-level Biotic Index (FBI). Calculations of the FBI overestimated impacts in clean streams and the underestimated impacts in polluted streams when the family tolerance factor was used where some species within that group were more sensitive than the family-level designation (Hilsenhoff 1988). Lenat and Resh (2001) indicated the potential for misidentification is more serious (missing exceptional streams at rate of 40 percent and not identifying poor sites at 28 percent). This had potentially caused lost protection at both ends (i.e., lost state resource water or other special designations and remediation for impairment that goes without remediation). A combination of some macroinvertebrates identified to genus / species and some groups at the family level might work best (Bailey, Norris, and Reynoldson 2001, Lenat and Resh 2001), but identifying macroinvertebrate taxa to the genus/species taxonomic level definitely lowered variability (Bailey, Norris, and Reynoldson 2001). This potential error caused by identifying only to family taxonomic levels or higher for all taxa calls into question volunteer monitoring data (at the family level) as being equal to indices like the HBI and the qualitative data sampling procedures in some states (e.g., North Carolina or Ohio at smaller drainage area sites) (Hilsenhoff 1988, Lenat 1987, 1988, OEPA 1987a,b, DeShon 1995, Engel and Voshell 2002). In contrast, Bowman and Bailey (1997) found high correlation with genus-level identification but with no “strikingly different description of community patterns” compared to taxonomic identification at the level of family or order. Scaling and scoring ranges for any PHWH indices needed to be checked for its appropriateness.

Metrics chosen for a PHWH ICI or a salamander quality index should respond to the likely effects of stressors and environmental factors causing ecological impacts (e.g., increased algal production, turbidity, more sedimentation, decreased flow) that affect the biological communities present in headwater streams (Karr et al. 1986, Plafkin et al. 1989, Barbour et al. 1992, Yoder and Rankin 1998, and Karr and Yoder 2004,). Various metrics were to be compared from different metric categories, such as EPT, tolerant, facultative, and trophic groups. Metrics were to be compared against chemical, habitat, and other physical measures (e.g., pool depth, substrate composition, riparian quality, canopy cover, temperature, nutrients) to illustrate and correlate related differences in quality.

Salamanders of various species within the lungless family Plethodontidae require the perennial flow and other habitat attributes found at PHWH Class III sites due to long-lived larval periods (OEPA 2002c). The data for the development of the PHWH classification system was collected from a systematic but random sampling throughout most of the state of Ohio that included reference sites and range of condition or disturbed sites. (OEPA 2002a,b,c,d). Utilizing reference sites and documenting a wide gradient range of human disturbance effects at the other PHWH sample sites is very important for understanding the species-environment relationships. This knowledge will guide the metric testing and performance, selection, score delineation and enumeration. When analyzing data and input effects, being thoughtful, practical and pragmatic about metric success (e.g., expected changes to community from stressor(s) delineating quality or diversity differences that are appropriate) is vital. With those ingredients present, then the chance of success at developing good headwater quality indices will be greater (Karr and Wu 1999).

The potential of evaluating, protecting, or restoring a PHWH stream can be best determined using indices developed from field data at least impacted reference watersheds. Metrics developed from this process can help determine primary headwater stream quality and metrics that can be diagnostic or point toward possible impacts. The PHWH indices should be helpful with site comparisons and for use in the development of biological criteria. Such monitoring evaluation tools also should allow more effective and wise management choices and directions for biomonitoring, protection, restoration or mitigation activities.

GOALS AND OBJECTIVES

My goal for this study is to develop biomonitoring tools for macroinvertebrates and salamanders for Class III Primary Headwater Habitat (PWHW) streams that are appropriate, achievable, reproducible, and effective in determining their biotic integrity.

The specific objectives of my research are:

1) to compare and contrast three quantitative sampling methods (Surber samples, artificial leaf pack samples, and bucket samples) and to determine the best and most appropriate quantitative sampling method among them to selected to use for quantitative sampling of PHWH stream sites (Chapter 2).

2) to develop a Primary Headwater Habitat Invertebrate Community Index (PHWH ICI) that responds and appropriately differentiates quality differences and community changes due to human disturbances or change of conditions (Chapter 2).

3) to develop a Salamander Community Quality Index (SCQI) for Class III PHWH streams that ranks diversity and quality appropriately and will respond and differentiate community quality differences and changes due to human disturbances or change of conditions (Chapter 3).

4) to combine the PHWH ICI and the Salamander CQI to form a composite community index of biotic integrity – the PHWH Community Quality Index (PHWH CQI). This index is for potential use to biomonitor the overall biotic integrity of Class III PHWH streams in Ohio and possibly elsewhere where appropriate groundwater hydrology and habitat structure is present (Chapter 4).

CHAPTER 2

DEVELOPMENT OF A PRIMARY HEADWATER HABITAT INVERTEBRATE COMMUNITY INDEX

INTRODUCTION

The stream continuum begins with small primary headwater streams (Vannote et al., Meyer et al. 2003). There are approximately five times as many of these capillary streams as larger streams in watersheds (Meyer et al. 2003, OEPA 2003a,b). Headwater streams make up 80% of the nation's stream network (Meyer et. al. 2003, OEPA, 2003c) and are critical for controlling water flow (preventing regular flooding), nutrients, and organic material downstream. The natural process of the decomposition and cycling of detritus, nutrient cycling, the cleansing of water and additives to it (e.g., like sediment, metals, phosphorus) begins at this smallest drainage area (Meyer et al. 2003). The biological quality of larger streams can usually be linked directly to headwater stream quality in its subwatersheds. Meyer et al. (2003) stated that 64% of inorganic nitrogen is retained or transformed within 915 meters after source entry into stream. Developing land, whether the causative agent(s) are suburbanization, agriculture, logging or mining effects, has caused many headwater streams to be filled, tiled, channelized, degraded and/or destroyed (Karr et al. 1986, Yoder and Rankin 1998, OEPA, 2003d). Many headwater streams have diminished capacity to absorb, retain, control, and /or recycle stormwater, nutrients, sediments, and organic matter (Meyer and Wallace, 2001, Miltner and Rankin, 1998). This allows continued nutrient and sediment transport downstream increasing eutrophication and negative impacts in larger stream and rivers (Resh et. al. 1988, Yoder and Rankin 1998, Meyer et al. 2003).

Five significant causes of impairment include: altered physical/riparian habitat (ditching or channelization or loss of riparian habitat); altered flows (possibly drainage tiling); increased sedimentation/siltation; organic enrichment; and nutrients (Karr and Yoder 2004). Pathogens are another impairment caused by large nonpoint and point source components (Karr and Yoder 2004). So the impetus for better assessment of the smallest headwater tributaries has been increasing, as it seems that the uppermost reaches of the river continuum (Vannote et. al. 1980 in Jones et. al. 1995) still bear the biggest brunt of impairment. There is a need for more detailed assessment, analysis and remediation jointly among many concerned constituents (Meyer et. al. 2003).

More ecological information is needed to be known of the species-environment relationship.

Most small streams (< 8.04 km^2) sampled in Ohio usually had been sampled qualitatively with a field assessment (presence/absence data with a minimal of narrative density information – low, moderate, or high density). Quantitative data was not collected because of lack of depth and flow limitations prevented valid quantitative sample data from Hester Dende colonizers to be collected. These small stream sample sites had been evaluated with a qualitative narrative assessment (DeShon et. al. 1980). Those are the exact limitations in quantitatively sampling primary headwater streams. The Primary Headwater Habitat (PHWH) Class III biotic community has been shown to consist of a sensitive invertebrate community of high species richness and diversity, yet there was an immediate need to get quantitative data to better define and illustrate the species-environment relationship (how PHWH biotic communities respond to stressors) to better evaluate and monitor these small PHWH streams in Ohio. Thus, a main goal of this study was to develop biomonitoring tools for macroinvertebrates to use in Class III Primary Headwater Habitat streams that were appropriate, achievable, reproducible, and effective.

STUDY AREAS AND METHODS

Site Selection

Sample sites were selected from various locations in central Ohio (*n*=7), north-central Ohio (*n*=8), and northeast Ohio (*n*=6) (Figure 2.1, Table 2.1).

Central Ohio sites were located in Delaware, Logan, and Pickaway Counties. Sample sites in north-central Ohio were located in Wayne County, and northeast Ohio sampling locations were located in Geauga, Lake, and Summit Counties. These sites were selected to capture varying site water and community quality from reference or least disturbed site to impacts from various chemical or physical inputs. The cluster of PHWH sites in the Upper Fork of Sugar Creek area in Wayne County are in streams within the largest dairy farm area in Ohio (Moore, 2002). Sites were geo-referenced with geographic positioning system (GPS) to include in geographical information system (GIS) landscape analysis. Quality of PHWH sites ranged from reference condition PHWH Class III (high quality exceptional sites – based on narrative quality assessments) to good to poor quality condition (range of condition sites) along the human disturbance gradient affected by differing negative anthropogenic impacts (OEPA 2008, Yoder and Rankin 1998) (Table 2.1). Reference condition sites contained consistent perennial, groundwater-fed coldwater with a high percentage of woody riparian vegetation in the stream corridor insulating the stream minimizing nonpoint source inputs and negative physicochemical inputs (OEPA, 2003c). Sample sites consisted of 100-m reaches. From the lowest downstream point the sampling reach was divided into three equal sampling zones for consistent chemical and biological sampling.

Figure 2.1. Primary Headwater Habitat (PHWH) stream sample sites for quantitative methods sample comparison and development of the Primary Headwater Habitat Invertebrate Community Index and Salamander Community Quality Index in Ohio during spring to fall 2004-05.

PHWH_Sites Tributary to Stream (Watershed)	Site Name	Quality Type	Narrative Quality	HMFEI	Latitude	Longitude
Cedar Run (Little Killbuck Creek)	NC1	Reference	Exceptional	48	40.881800	-82.034800
Chagrin River	NE3	Reference	Exceptional	36	41.552310	-81.234590
Silver Creek (Chagrin River)	NE2	Reference	Exceptional	47	41.457450	-81.329280
Big Darby Creek	C5	Reference	Exceptional	49	40.299283	-83.571167
Slate Run (Walnut Creek)	C9	Reference	Exceptional	49.5	39.757200	-82.842200
Silver Creek (Chagrin River)	NE6	Reference	Exceptional	49	41.456100	-81.300800
Sugar Creek (Tuscarawas River)	NC11	Range of Condition	Good	28	40.864830	-81.840675
Sugar Creek (Tuscarawas River)	NC7	Range of Condition	Very Poor - Poor	6	40.851697	-81.862351
Sugar Creek (Tuscarawas River)	NC3	Range of Condition	Poor - Fair	7	40.885628	-81.886807
Sugar Creek (Tuscarawas River)	NC8	Range of Condition	Fair	21	40.859074	-81.867698
Sugar Creek (Tuscarawas River)	NC10	Range of Condition	Marginally Good - Good	22	40.871598	-81.827279
Sugar Creek (Tuscarawas River)	NC9	Range of Condition	Good	28	40.860453	-81.864649
Pierson Creek (East Br. Chagrin River)	NE5	Reference	Very Good - Exceptional	42	41.612163	-81.369690
Big Darby Creek	C2	Reference	Exceptional	42	40.299400	-83.571367
Little Killbuck Creek (Killbuck Creek)	NC2	Reference	Very Good - Exceptional	30	40.821100	-82.021100
Big Run (Olentangy River)	C6	Range of Condition	Fair - Marginally Good	21	40.203769	-83.038268
Big Run (Olentangy River)	C8	Range of Condition	Marginally Good - Fair	27	40.213767	-83.036800
Olentangy River	C7	Reference	Exceptional	46	40.148200	-83.031200
Big Run (Olentangy River)	C3	Range of Condition	Fair - Good	26	40.206167	-83.037783
Tinkers Creek (Cuyahoga River)	NE1	Range of Condition	Fair	21	41.341920	-81.481170
Spring Creek (Cuyahoga River)	NE4	Range of Condition	Good to ~ Very Good	30	41.258360	-81.579310

Table 2.1. Primary Headwater Habitat (PHWH) sample sites from Ohio sampled in spring to fall 2004-05 with receiving stream and watershed, site name, site number, quality type (Reference or Range of Condition), narrative quality, Headwater Macroinvertebrate Field Evaluation Index (HMFEI) scores, and latitude/longitude used for development of the Primary Headwater Habitat Invertebrate Community Index and Salamander Community Quality Index.

Physicochemical and Land Use Analysis Data Collection

Landscape analysis data from geographical information systems (GIS) and physicochemical data and were collected at all PHWH sample sites to document the influence of adjacent and watershed-wide land use inputs related to the invertebrate community quality. Habitat parameters included chemical, physical stream structure, and land use measurements. Portions of the Headwater Habitat Evaluation Index (HHEI), like pool depth and substrate scores, were measured (OEPA, 2002a). Percent forest cover and gradient were calculated using the United States Geological Survey (USGS) Streamstats program (Koltun 2002, 2006). Measurements were collected at the downstream sample point (0 m) and at 33- and 66-m marks. Temperature (°C), dissolved oxygen (mg/L), pH, turbidity, and conductivity (μmhos/cm^3) and were measured using an YSI 6000 multi-probe data sonde probe (Yellow Springs Instruments, Yellow Springs, Ohio). Parameters with multiple measurements (e.g., % open canopy cover or bankfull width) were averaged across sample reaches. A densiometer was used to measure percent canopy cover by taking measurements upstream, downstream, and perpendicular to both banks at each reach mark with the three means averaged (USEPA 2006). Algal Cover Index was given an overall score 1-5 based on visual and tactile characteristics (USEPA 2006). Qualitative habitat evaluations were conducted using the HHEI (OEPA 2002a) according to OEPA protocols. These environmental metrics from the HHEI scored separately included substrate score (% total slabs / boulder / bedrock / cobble), % silt and muck, riparian width (visual measure), sinuosity, and floodplain quality (OEPA 2002a). Floodplain quality scored 0-20 with 10 possible points per bank based on observed predominant habitat (e.g., mature forest, residential, fenced pasture, row crop, or construction). Adjacent land use and the land use perpendicular to the stream channel were visually assessed for the presence or absence of woodlots, feedlots, row crop, and residential areas. Embeddedness scores were visual assessments with the 1 to 5 score range or 1-20. Embeddedness 1-5 scored a 5 if silt covered < 5% of stream substrates with a 1 scored for > 75% silt covered conditions (Platts et al. 1983). Land use spatial analysis that used ArcGIS 9.2 with fifteen land cover data layers from the 2001 National Land Cover Data (NLCD) was conducted (USEPA, 2001). Measured land use variables included residential housing intensity (low, moderate, and high), impervious surface, different forest types, open water, pasture hay, and cropland among others (Appendix Tables A.7-A.9).

Macroinvertebrate Sample Collection

Macroinvertebrate samples were collected starting in fall 2004 with the majority of sampling occurring in spring (May) 2005 to fall (November) 2005. Quantitative macroinvertebrate sampling for three quantitative methods (artificial leaf packs, Surber samples, and bucket samples) resulted in total count data collected at all 21 sites (Davic and Skalski 2009, Surber 1953, OEPA 2008, USEPA 2006). Qualitative macroinvertebrate samples (micro-niche sampling of all habitats existing in sample stream reach resulting in presence / absence data) were collected at all 21 sample sites (OEPA 2008).

Qualitative Macroinvertebrate Sampling

Qualitative macroinvertebrate samples were collected and recorded as presence / absence data at all sites. All niches or microhabitats in a sample stream reach were sampled using a dip net via kick sampling or jabs which dislodged organisms and/or by manually checking larger habitat types (e.g., rubble, boulders, wood, logs, rip rap, aquatic macrophytes). The collection location of aquatic macroinvertebrates was documented for each habitat area: riffle, run, pool, and margin. Organisms were collected and placed in a sample collection jar filled with 95% ethyl alcohol (EtOH) for laboratory identification to appropriate taxonomic levels (OEPA 2008).

Quantitative Macroinvertebrate Sampling

Quantitative macroinvertebrate sampling was conducted with artificial leaf packs, Surber samples, and bucket samples at all 21 sample sites. Six sampled reference sites (two from each region) were identified and totaled with all replicates from each method totaled separately. The cumulative totals for each quantitative method from these 6 reference sites were analyzed and compared to help determine the best macroinvertebrate quantitative method sampled. The quantitative macroinvertebrate samples from the preferred sampling method from the remaining reference and range of condition (disturbed) sample sites were composited (combined into one sample / site) and identified for analysis according to OEPA protocols (OEPA 2008).

Artificial leaf packs consisted of a three sets of three 25 cm X 25 cm mesh bird netting (15 mm mesh) filled with 20 rolled tubes of gray polypropylene weed control fabric formed from a piece of fabric 15 cm X 10 cm which was stapled forming an initial diameter of approximately 5.08 cm (Davic and Skalski 2009). With regard to benthic macroinvertebrate colonization, the total surface area sampled from the artificial leaf packs at a sample site was 1.29 m^2. Preliminary experiments I conducted with these artificial leaf packs confirmed sampling conditions were best from spring (April) (after ice-out) to end of fall as recommended by Ohio EPA (OEPA, 2002). Preliminary determinations at two reference sites indicated (based on diversity and recovery - or losses at longer colonization periods) the optimum colonization period was 7-10 days. A total of nine leaf packs were placed into each sample stream. They were collected within the colonization period of 7-10 days.

Artificial leaf packs were collected in the field by first carefully removing rocks anchoring leaf packs. Next the string connecting the artificial leaf packs are cut so as to collect one at a time. Then a pan was slid carefully but quickly under the leaf pack and lifted out of the water. The whole artificial leaf pack, with its contents, were preserved with 95% EtOH and taken back to separate contents for identification of the three replicates at the sample site.

Surber samples were collected using the Surber substrate sampler in the 100-m sample reach near the 0-m (downstream end of stream reach), 33-m, and 66-m reach mark at each sample site (Surber 1953). The Surber sample is attached to a 500 um mesh collection net The Surber sample, with a sample area of 929 cm^2, was collected in a riffle or shallow run reach. The substrates inside the sample area were agitated or stirred for five minutes. Cases or insect retreats on larger substrates are physically rubbed off into the collection net. Each replicate was removed from the collection net and preserved in a container with 95% ethanol (EtOH) for sample processing and later identification in lab. The three replicates together comprised the quantitative Surber sample for that sample site. The total area sampled equaled 0.28 m^2 for the composite Surber sample at each site.

Bucket samples were collected every 10-12 m through the 100-m sample reach with a bottomless 5 gallon bucket. A weighted skirt was attached around the bottom edge of the bucket to define, contain and separate the sample area. Bottom of the bucket was pushed into the bottom substrates if possible up to 3-5 cm if needed to help hold the bucket stationary in the replicate sample area. Larger rocks or wood was pulled out and placed into a collection pan to physically rub off macroinvertebrates or retreat cases which are placed or poured into a No.60 (250 mm) mesh screen sieve. After the larger rocks or sticks were removed, the stream water contained inside the bucket was agitated to suspend the aquatic organisms. Then the suspended organisms were netted out three times with a fine mesh net and placed in the No. 60 mesh sieve. The whole sample was collectively rinsed in the No. 60 sieve with stream water to remove silt or some mud. Then the sample was placed into a collection jar with 95%

EtOH for future processing and identification following OEPA protocols (USEPA 2006, OEPA 2008). A total of eight replicates through the sample reach were collected with approximately half of the replicates collected in erosional areas (riffles/runs) and half collected in depositional zones (pools). These eight replicates represented the bucket sample at one sample site, and the total area sampled was 0.42 m^2.

The Bucket quantitative samples that were collected were processed and identified according to OEPA protocols (OEPA, 2008) except that initially the smallest size sieve (No. 60) (0.250 mm) was stacked underneath a No. 30 sieve (0.600 mm) and the normally smallest used No. 40 sieve (0.425 mm). The No. 60 sieve contents were determined to be composed primarily of silt with very few organisms present (< 0.1 of 1%) not changing the structure or density of the quantitative samples. The No. 60 sieve (0.425 mm) contents were then quickly scanned with the very few organisms placed in with the No. 40 screen organisms. The smallest macroinvertebrates (e.g., water mites (Hydrachnidia) and oligochaetes) were consistently collected in the No. 30 and No. 40 screen sieved samples. A prescreening pick through the whole sample was conducted to remove all unique aquatic organisms for identification. Then samples were, if needed (due to high densities), subsampled with a sample splitter down to 300-500 total organisms, identified, and extrapolated to get final total taxa identified with relative densities to expedite processing. I scanned at least 1/8 to 1/4 of the sample regardless of subsample fraction to make sure new taxa were not missed (OEPA 2008).

Quantitative Sampling Methods Comparisons

In decreasing order of stream surface area sampled for benthic macroinvertebrates per stream, the three sample methods were as follows: artificial leaf packs (1.28 m^2), bucket (0.42 m^2), and Surber (0.28 m^2). Data from quantitative sampling methods comparison was analyzed with Multi-Response Permutation Procedures (MRPP) in PCORD (McCune and Grace 2002, Quinn and Keogh 2002, Zimmerman et al. 1985). An alpha level of $\leq$ 0.05 indicated statistically significant *P* values. Analyses were run individually against each quantitative sample data set and globally with all three together. The three sample methods were a bucket method (USEPA 2006), artificial leaf packs, and the Surber method. Comparisons were made with and without chironomid midges. The matrices of data sets analyzed were as follows: count totals with midge counts as Chironomidae (family); relative density totals with midge counts as Chironomidae (family); count totals with individual chironomid spp./groups (chironomid spp. only); relative density totals with individual chironomid spp./groups (chironomid spp. only); count totals without chironomids; and relative density totals without Individual chironomids. Summary Statistics on data sets from analyses included species richness (S), evenness (E), Shannon diversity index (H), and Simpson's Diversity Index (D).

Environmental Variables

Nineteen environmental variables from the total measured (69) were selected for use in further statistical analysis to select the final invertebrate metrics. Invertebrate metric groups were compared to each other after some were transformed to decrease kurtosis and improve homogeneity of variance and normality (if possible). Original data was analyzed if transformations did not significantly improve distribution, normality, or correlation. Different graphs of environmental variable data were created using R (R Development Core Team 2008). Less informative environmental variables (less scope, no difference between reference data and disturbed site data) were eliminated through comparisons of histograms, quartile plots, and box plots showing distributions and separation and ranges between the reference sites and the range of condition sites. Correlations of the environmental variables to the established independent HMFEI and HHEI index scores were compared among metrics. The environmental metrics were ranked by their correlations to HMFEI and HHEI. The most highly positively or highly negatively correlated invertebrate metrics were kept, while less correlated invertebrate metrics were eliminated. Some environmental variables were also eliminated by their redundancy to each other (similar metric or $r \geq 0.8$ or higher). Eventually 19 environmental variables (n =21 sample sites - 2) were selected for further use in additional statistical analyses to gain understanding of the species-environment relationships, and with that insight help facilitate final invertebrate metrics selection for the PHWH ICI.

Metrics Development and Statistical Analyses

A total of 266 macroinvertebrate (invertebrate) metrics (no transformations) were initially created and were distributed among variable type categories including: general totals or ratios, sensitive (involving sensitive taxa), EPT, mayfly, caddisfly, and stonefly categories. Other metric categories included coldwater (CW), midges, trophic (type of feeding guild), tolerant, and facultative groups (ubiquitous, or possible thriving in some deteriorating quality conditions). Invertebrate metric groups were compared to each other after some were transformed to decrease kurtosis and improve normality (if needed). Different graphs of invertebrate metric data were created using R (R Development Core Team 2008). Less informative invertebrate metrics were eliminated through comparisons of histograms, quartile plots, and box plots showing distributions and separation and ranges between the reference sites and the range of condition sites. Correlation of the individual metrics with the independent qualitative HMFEI scores and HMFEI total scores were compared. The highly positively correlated ($r \geq 0.7$) or highly negatively correlated (≥ -0.6) invertebrate metrics were kept, while less correlated invertebrate metrics were eliminated. Invertebrate metrics were also eliminated by their redundancy with each other (r values ≥ 0.8 with most ≥ 0.9). The number of possible final invertebrate metrics with which to develop a PHWH ICI was reduced to 50 metrics. More statistical analyses were conducted to gain insight and illustrate the species-environment relationships which helped in the final selection of invertebrate metrics and the development of the PHWH ICI.

The remaining invertebrate metrics were merged with the condensed invertebrate taxa data file to form an invertebrate taxa data set. A Redundancy Data Analysis (RDA) was conducted to gain information about the species – environment relationship. The RDA was conducted using the species data (merged invertebrate metrics and the condensed invertebrate data) against the environmental variables and sample sites in CANOCO (ter Braack and Smilauer, 2002, Leps and Smilauer, 2003). RDA, a linear ordination technique where the amount of variance from one set of variables is correspondingly correlated (or redundant) to a combination of another set of variables and the proportion of variance accounted for can be calculated, was conducted as a direct gradient analysis between the species and environmental data (McGarigal et al. 2000, ter Braack and Smilauer, 2002). The invertebrate metrics were made passive – not influencing the position of the invertebrate taxa relative to the environmental variables. Various biplot graphs of the combinations of species data, sample sites, and/or the environmental vectors as related to each other (distinguishing and separating range of quality or relatedness) were created. Most importantly, a triplot graph of the species data (merged invertebrate metrics and condensed invertebrate data) against the environmental variables and sample sites was created from the RDA analysis in CANOCO from which further related analyses were conducted (ter Braack and Smilauer, 2002).

From the RDA analysis the invertebrate metrics biplot scores alone and the merged invertebrate metric and species biplot scores were transformed into separate data files and imported into PCORD to derive individual Euclidean Distance Matrices (Wards Method) which produced a Hierarchical Cluster Analysis (McCune and Grace 2002, Leps and Smilauer, 2003). The Euclidean Distance Matrix Results produced a unique hierarchical cluster analysis that divided the invertebrate metrics into different clusters (e.g., like kin) based on their distance (or closeness in space) as illustrated on the RDA triplot graph. The final invertebrate metrics were selected out of these hierarchical clusters for the Invertebrate Community Index (ICI). Final invertebrate metrics for the PHWH Invertebrate Community Index (ICI) were selected from each cluster group after comparisons of utility (amount of information), their location in space in relation to environmental vectors, species, and sample sites, distance to each other (redundancy), scope, and the ability to reflect a wide range of conditions while distinguishing reference sites from disturbed sites. These comparisons were from statistical and empirical analyses of quantitative and qualitative sample data collected at Class III PHWH sample sites.

Final Invertebrate Metrics Scoring

Each final metric was plotted on a scatter plot using statistical analysis software (Kaleidograph, Synergy Software Version 4.01, 2005) to check for any drainage area influences which were normal in larger streams (Yoder and Rankin 1995). The reference condition sites were plotted beside the range of condition sites for each metric to show distribution relationships and separation between the reference sites and other sites.

A cumulative frequency curve was created that indicated the data for that final metric had a linear or more complex relationship with a reported coefficient of variation (r^2). Then a final metric scoring curve was created to allow for continuous scoring between 0 and 1 (Mebane, Maret, and Hughes 2003). The exact slope of the scoring line was determined by selecting what particular reference site value (total, percentage, or proportion) attained a full metric score of 1. Some curvilinear metric scoring equations also had a zero metric score determined to be above the x axis (normally the zero score) which was determined.

After determining each individual metric score between 0 and 1 with graph and equation, each metric score was multiplied by its total point value (dependent upon total number of metrics selected) and all metric totals are added together. Then the summed total was then adjusted with a constant to total 100 possible points. That score was the Primary Headwater Habitat Invertebrate Community Index.

RESULTS

I analyzed 11 artificial leaf pack samples (X 3 replicates/sample), and 6 Surber samples (X 3 replicates/sample), and 21 composite bucket samples (X 8 replicates/sample) among the 21 PHWH sample sites. I identified over 70,000 macroinvertebrates to different taxonomic levels (order, family, genus, or species) depending on taxa group.

Preliminary Leaf Pack Colonization

Leaf pack colonization period was determined by comparing colonization data for weeks 1-4 at 2 reference sites: C7 and NC1. At site C7, only week 1 colonizers were recovered on 6/8/05 after 8 days in stream. The week 2 (14-day) colonizers were dry. The week 3 and 4 colonizers were removed and not recovered when checked after 3-weeks colonization (vandalism). Five of 23 taxa collected from week 1 data were EPT taxa (22%) and totaled 56 of 156 organisms (35.9%). Midges totaled 58% of organisms collected. The week 1 sample population seemed to be a representative sample (taxa richness of 23 taxa) compared to a qualitative sample collected in May 2005 (25 taxa).

Leaf pack colonizers were recovered at site NC7 during all 4 weeks. Week 1 colonizer results contained 17 EPT taxa of 52 total taxa (32.6%), and EPT taxa were 37.6% of all total organisms collected. Midges totaled 57% of collected organisms. Week 2 colonizer results were similar with 30% of taxa collected were EPT taxa (16 of 53). Diversity totals collected from week 1 and 2 colonizer data were similar (52 to 53, respectively). Week 3 and 4 colonizer results were different, as taxa diversity decreased (37 and 49, respectively). The % total midge count dominated the collected invertebrate community at 87% and 91, respectively, for weeks 3 and 4 colonizer data. Conversely, the % EPT taxa (of total count) decreased to 12.5% and 8.8%, respectively, for weeks 3 and 4 data.

Week 1 totals for % EPT organisms and % midge totals for site NC7 were similar to site C7 and past empirical data collected in Ohio at Ohio EPA (DeShon 1995). Week 2 data was similar with no increased taxa diversity. Potential loss of colonizers to frequent or sudden spring and fall rain events (washed out or buried) or vandalism (very easily seen in shallow water) was a practical issue (which occurred at one of the test sample sites). With similar data at both sites for week I and little change in week 2 data from site NC7, the leaf pack colonizer time range selected for the research study was 7-10 days.

Quantitative Sample Methods Comparison

Summary statistics on data sets from analyses included species richness (S), evenness (E), Shannon diversity index (H), and Simpson's diversity index (D). Species richness (S) and diversity were highest in the bucket samples in all cases at each of the six sample sites among non-midge taxa (Tables 2.2 -2.3). The mean (+/- 1 standard error (s.e.)) total species for the bucket samples were 53.5 (s.e. of 2.0) which was higher compared to the surber and leaf pack totals (mean of 40.7 (s.e. of 2.2) and 25.3 (s.e. of 4.5), respectively). The standard errors of species richness did not overlap between the bucket method and Surber or the leaf pack methods (Table 2.2).

There was no distinguishable difference between the Shannon diversity index and the Shannon evenness scores for the bucket and Surber Methods. The leaf pack method results were much lower and significantly different from the bucket sample results for the Shannon diversity index (no overlap of standard error between groups). The Evenness scores were quite similar for the bucket and surber sample data, and the leaf pack samples were less with more variability. The Simpson diversity indices (D) were very similar between bucket and surber samples with the leaf pack mean Simpson D Index 20% lower with much greater variability. The Simpson evenness (E_D) value for the leaf pack sample was higher than both the bucket and surber samples due to the artifact of 40 to 110 percent less species diversity which inflated the Evenness values for the leaf pack sample data (Table 2.2).

Comparisons of the midge species among the quantitative methods indicated the bucket method data showed significantly higher diversity with all of the Species richness totals higher versus the bucket method totals at all six sample sites (Table 2.3). The Shannon diversity index for the bucket method had a higher mean among the Chironomids but all the standard deviations overlapped. There was no difference in the Simpson Diversity Index, as all were similarly distributed. The bucket sample data, due to large populations of a few taxa along with the smaller numbers of a diverse midge population, was more uneven(E_H) compared to the surber sample and more similar to the leaf pack samples.

		Count Totals exclude all midges			
Sample Type	Quant. Data Set	Species Richness (S)	Evenness (E)	Shannon Index (H)	Simpson Index (D)
Total	Mean	39.8	0.627	2.29	0.793
Total	Std. Error	3.27	0.024	0.13	0.031
Bucket	Mean	53.5	0.649	2.578	0.856
Bucket	Std. Error	1.97	0.033	0.127	0.029
Leaf Pack	Mean	25.3	0.554	1.778	0.683
Leaf Pack	Std. Error	4.5	0.044	0.217	0.064
Surber	Mean	40.7	0.678	2.514	0.838
Surber	Std. Error	2.2	0.041	0.182	0.042

Table 2.2. Summary data totals of Primary Headwater Habitat quantitative sampling methods comparison analysis for artificial leaf pack, bucket, and Surber sample data. Mean counts or values for Species Richness, Evenness, Shannon Diversity Index, and Simpson Diversity Index with their standard errors for data collected at selected sample sites in Ohio in spring to fall 2004-05.

		Totals include all midges as family Chironomidae			
Sample Type	Quant. Data Set	Species Richness (S)	Evenness (E)	Shannon Index (H)	Simpson Index (D)
Total	Mean	40.83	0.494	1.816	0.673
Total	Std. Error	3.27	0.031	0.133	0.039
Bucket	Mean	54.5	0.468	1.875	0.671
Bucket	Std. Error	1.98	0.038	0.165	0.055
Leaf Pack	Mean	26.3	0.395	1.262	0.536
Leaf Pack	Std. Error	4.47	0.043	0.133	0.064
Surber	Mean	41.7	0.62	2.312	0.812
Surber	Std. Error	2.19	0.362	0.157	0.029

Table 2.3. Summary data totals of Primary Headwater Habitat quantitative sampling methods comparison analysis for artificial leaf pack, bucket, and Surber sample data. Mean counts or values for Species Richness, Evenness, Shannon Diversity Index, and Simpson Diversity Index with their standard errors for data collected at selected sample sites in Ohio in spring to fall 2004-05.

Analysis Group / Comparison	Test Statistic T	Probability (*P*)
Counts with midge family (Chironomidae) totals		
Global	-3.476	**0.005**
Bucket vs. Leaf Pack	-2.049	**0.038**
Bucket vs. Surber	-5.172	**0.001**
Leaf Pack vs. Surber	-0.725	0.207
Counts without midge totals		
Global	-0.975	0.161
Bucket vs. Leaf Pack	-2.117	**0.030**
Bucket vs. Surber	-0.097	0.422
Leaf Pack vs. Surber	-0.143	0.407
Chironomid midge species / group totals		
Global	-1.554	0.074
Bucket vs. Leaf Pack	-0.094	0.427
Bucket vs. Surber	-3.418	**0.002**
Leaf Pack vs. Surber	-0.686	0.211
Relative Density with midge family totals		
Global	-5.576	**<0.001**
Bucket vs. Leaf Pack	-5.264	**0.001**
Bucket vs. Surber	-3.538	**0.004**
Leaf Pack vs. Surber	-2.695	**0.014**
Relative Density without midge totals		
Global	-4.029	**0.001**
Bucket vs. Leaf Pack	-5.638	**<0.001**
Bucket vs. Surber	0.1483	0.518
Leaf Pack vs. Surber	-3.517	**0.003**
Relative Density of midge species / groups		
Global	-2.5	**0.015**
Bucket vs. Leaf Pack	-3.081	**0.006**
Bucket vs. Surber	-1.474	0.076
Leaf Pack vs. Surber	-0.505	0.282

Table 2.4. Summary statistical results of Individual and global comparisons of Multi-Response Permutation Procedures (MRPP) for Primary Headwater Habitat quantitative sampling methods comparison data sets (artificial leaf packs, bucket, and Surber samples) sampled in selected Ohio stream sites in spring to fall 2004-05. Statistical significant *P* values were in **bold**.

After combining the species total counts for both sets of invertebrate data the bucket sample data again accounted for greater species richness differential among all six sites. There was a significant difference in species richness, as the bucket sampling contained a mean taxa count of 101.3 (s.e. = 4.4). There were averages of 30% and approximately 50% less total taxa collected by the Surber and leaf pack methods, respectively. The range for the bucket samples was completely unique compared to the other methods, as the standard errors did not overlap.

For more direct comparisons with MRPP analyses the count data was analyzed with the midges at different taxonomic levels or removed. In the MRPP analyses using the Sorenson (or Bray-Curtis) distance measure for total counts (with Chironomidae only (family level)) there was statistically significant differences in the global comparisons (P=0.005) and the two-way comparisons between bucket and Surber methods (P <0.001). The bucket and leaf pack MRPP analysis also indicated statistically significant diversity differences between groups (P= 0.038) (Table 2.4). The total count data without midges was significant only between the bucket method and the leaf pack samples (P=0.030). The bucket and Surber sample comparison for the chironomid species / group totals analysis was also statistically significant (P= 0.002) (Table 2.4).

Relative density total comparisons also indicated significant results. The results for taxa relative density with all midges as family Chironomidae indicated statistically significance in all analyses (P<0.001 - 0.014) with the bucket method results having higher relative densities comparatively. The MRPP analyses for the relative density for all taxa without midges showed statistical significance in all tests (range of $P<0.001$ to 0.003) except the bucket vs. Surber comparison. The midge species / group relative density data set was statistically significant in the global comparison and bucket versus leaf pack comparison (significant at P=0.015 and 0.006, respectively) (Table 2.4).

In addition, using the total taxa counts (without midges) and a relative density comparison ranking (1, 2, or 3) of Ephemeroptera / Plecoptera / Trichoptera or EPT taxa and subgroups within mayflies and caddisflies for all six sites (with 25 comparisons), the bucket data subsets were ranked first or tied for first rank in the majority of the categories (112 of 144 comparisons or 78%) with 99% in the first two ranks (only one third rank score). The Surber sample data ranked intermediate with many comparisons ranked first (24%) and second and was more strongly represented with higher count totals and relative densities than the leaf pack samples. The mean rank for the bucket sample data was 1.23 (se of 0.037) which was significant, as there was no overlap of the means with std. error ranges of the surber or leaf pack data mean ranks (1.88(se of 0.005) and 2.71 (0.049), respectively).

The leaf pack method was ranked first only ten times or 6.9 percent of comparisons. Leaf pack count totals ranked first were very similar and not significantly different than the other sampling group totals. This scenario occurred in mostly three ways: via the number of taxa of subgroups (like heptageneid / ephemerellid mayfly taxa); or it occurred where stoneflies, case-building caddisflies or caddisflies were total counts and less dependent on cases (e.g., philopotomids or rhyacophilids) and can move more independently of substrate (migrate); or at a particular site (i.e., West Woods Trib. to Silver Creek) where it had a lower gradient, averaged smaller substrates, and more organic material naturally , so there was less dependence on rock substrates by more taxa. Most caddisfly comparisons placed the leaf pack sample method third rank. The leaf pack samples contained much lower numbers of hydropsychid caddisflies (e.g., *Ceratopsyche, Diplectrona, Parapsyche,* and *Hydropsyche* sp.), fewer sessile, attached case-building caddisflies (like *Pycnopsyche* sp., polycentropids, and *Neophylax* sp.), and fewer rare cased caddisflies (i.e., *Glossosoma, Ironoquia, Frenesia, Goera,* and *Lepidostoma* sp.) than were collected in the bucket and Surber samples.

In summary, through various comparative and statistical analyses of the quantitative macroinvertebrate data from the quantitative sample methods comparison, the bucket method collected the highest diversity and most complete quantitative macroinvertebrate data collection in the PHWH samples. Analysis of quantitative data from the six selected PHWH sample sites determined that the USEPA Bucket sample method data performed best and was used for the PHWH quantitative data analyses for the PHWH index development.

Environmental Metrics

Nineteen of 69 physicochemical, habitat and land use parameters were selected to use in the final metric selection process. Differences between reference sites and range of condition sites were evident in most variables. Nutrient inputs, canopy cover, forest cover, and temperatures were lower with wide riparian widths at most reference sites (Tables 2.5-2.6, Tables A.7-A.9). In contrast, percent impervious surface, cropland, residential percentages, and open canopy were higher at disturbed sties (Tables 2.7-2.8, Tables A.7-A.9). Summary data tables for the selected environmental variables were separated into PHWH reference sites and non-reference or range of condition sites. The environmental variables with the highest absolute correlation between the independent indices HMFEI and HHEI were selected (Table 2.9). Eight positively correlated environmental variables were selected. The highest positively correlated environmental variables were substrate score (a partial component of the Headwater Habitat Evaluation Index -HHEI), embeddedness (low), and riparian width (m). Eleven negative environmental variables were selected with the most correlated being percent silt and muck (%), temperature (^{o}C), and percent open canopy (ratio). Other selected environmental variables were percent forest cover (ratio), log gradient, log conductivity (micromhos/cm), dissolved oxygen (DO) (mg/l), turbidity, maximum pool depth (cm), floodplain quality score, residential (presence/absence), total suspended solids (TSS), total ammonia (NH_3) (milligrams/liter), log total Kjeldahl nitrogen (TKN) (mg/l), total phosphorus (TP) (mg/l), and percent cropland (ratio) (Table 2.9).

Sample Sites (Reference)	C2	C5	C7	C9
Headwater Habitat Evaluation Index				
substrate score	22	29	29	33
Embeddedness (1 to 5)	3	3	4	4
Riparian width (meters)	151	81	155	340
Dissolved oxygen (mg/l)	10.73	10.87	10.6	8.8
Forest cover (ratio)	0.291	0.438	0.574	0.489
Maximum pool depth (cm)	40.0	28.0	22.0	33.0
Floodplain quality score	16	16	20	20
Log gradient (meters / km)	0.418	0.413	0.379	0.364
Silt and muck (ratio)	0.20	0.08	0.01	0.01
Temperature (^{o} Celsius)	9.97	10.37	13.37	13.5
95% confidence intervals	0-28.66	7.43-13.31	0-27.67	
Open canopy (ratio)	0.028	0.047	0.050	0.077
95% confidence intervals	0-0.136	0-0.159	0-0.125	0-0.541
Total suspended solids (mg/l)	4.99	4.99	4.99	4.99
Total phosphorus (mg/l)	0.009	0.009	0.009	0.013
Log total Kjeldahl nitrogen (mg/l)	-0.721	-0.721	-0.678	-0.721
Cropland (ratio)	0.444	0.124	0.000	0.100
Total ammonia (mg/l)	0.049	0.049	0.049	0.049
Residential area (presence/absence)	0	0	1	0
Log conductivity (micromhos/cm)	2.862	2.946	2.786	2.771
95% confidence intervals			2.771-2.801	
Log turbidity (Nephelometric Turbidity Units)	0.778	0.792	-0.398	0

Table 2.5. Summary data for selected environmental variables (physicochemical and land use parameters) from Primary Headwater Habitat reference sites sampled in central Ohio from spring to fall of 2004-05.

Sample Sites (Reference)	NC1	NC2	NE2	NE3	NE5	NE6
Headwater Habitat Evaluation						
Index substrate score	27	27	34	36	18	21
Embeddedness (1 to 5)	5	4	5	5	5	5
Riparian width (meters)	500	377	750	235	300	400
Dissolved oxygen (mg/l)	9.04	7.12	10.81	10.37	7.93	10.41
95% confidence intervals	5.10-12.98		6.78-14.84		7.39-8.47	9.94-10.88
Forest cover (ratio)	0.240	0.946	0.608	0.585	0.464	1.000
Maximum pool depth (cm)	12.0	29.5	28.0	24.6	12.5	22.0
Floodplain quality score	20	20	20	20	20	20
Log gradient (m / km)	0.403	0.464	0.353	0.384	0.413	0.49
Silt and muck (ratio)	0.00	0.01	0.02	0.05	0.00	0.05
Temperature (^{o} Celsius)	12.49	15.30	11.09	11.87	16.70	13.30
95% confidence intervals	7.07-17.91		0-22.85	0.82-23.4		11.55-15.05
Open canopy (ratio)	0.096	0.054	0.070	0.097	0.113	0.103
95% confidence intervals	0.061-0.131	0.052-0.56	0.045-0.095	0-0.206	0.076-0.15	0.084-0.122
Total suspended solids (mg/l)	4.99	6.00	4.99	5.49	4.99	7.50
Total phosphorus (mg/l)	0.038	0.010	0.009	0.068	0.104	0.010
Log total Kjeldahl nitrogen (mg/l)	-0.699	-0.721	-0.745	-0.648	-0.721	-0.721
95% confidence intervals			-3 - 0.346			
Cropland (ratio)	0.569	0.000	0.095	0.000	0.548	0.000
Total ammonia (mg/l)	0.049	0.216	0.049	0.050	0.049	0.049
Residential area (presence/absence)	0	0	0	1	0	0
Log conductivity (micromhos/cm)	2.643	2.699	2.372	2.613	2.313	2.313
95% confidence intervals	2.63-2.66	2.59-2.81	2.18-2.57		2.29-2.34	2.25-2.38
Log turbidity (Nephelometric Turbidity Units - NTU)	-0.004	0	0	0.21	0	0

Table 2.6. Summary data for selected environmental variables (physicochemical and land use parameters) from Primary Headwater Habitat reference sites sampled in north-central and northeast Ohio from spring to fall of 2004-05.

Sample Sites (Reference)	C3	C6	C8	NE1	NE4
Headwater Habitat Evaluation Index substrate score	33	35	33	27	29
Embeddedness (1 to 5)	5	5	4	4	5
Riparian width (meters)	95	100	29	19	107.5
Dissolved oxygen (mg/l)	12.36	13.31	9.16	8.86	8.56
Forest cover (ratio)	0.349	0.267	0.330	0.323	0.452
Maximum pool depth (cm)	32.5	25.0	28.0	15.0	34.0
Floodplain quality score	20	19	16	12	18
Log gradient (m / km)	0.328	0.365	0.303	0.435	0.437
Silt and muck (ratio)	0.00	0.050	0.050	0.110	0.050
Temperature (^{o} Celsius)	17.28	15.29	17.4	16.90	17.15
Standard Error	0.72	1.79			
95% confidence intervals	14.17-20.39	0-38.03			
Open canopy (ratio)	0.008	0.086	0.092	0.133	0.095
Standard Error	0.001	0.015	0.025	0.023	0.015
95% confidence intervals	0.002-0.014	0.02-0.152	0-0.198	0.036-0.23	0.029-0.161
Total suspended solids (mg/l)	4.99	14.00	5.00	4.99	4.99
Total phosphorus (mg/l)	0.023	0.009	0.107	0.010	0.009
Log total Kjeldahl nitrogen (mg/l)	-0.367	-0.377	-0.420	-0.051	-0.208
Cropland (ratio)	0.161	0.310	0.286	0.000	0.310
Total ammonia (mg/l)	0.049	0.049	0.049	0.087	0.049
Residential area (presence/absence)	1	1	1	1	0
Log conductivity (micromhos/cm)	2.961	2.958	2.724	3.247	3.173
Log turbidity (Nephelometric Turbidity Units - NTU)	0.602	1.380	0.908	0	0

Table 2.7. Summary data for selected environmental variables (physicochemical and land use parameters) from Primary Headwater Habitat non-reference sites sampled in central and northeast Ohio from spring to fall of 2004-05.

Sample Sites (Reference)	NC3	NC7	NC8	NC9	NC10	NC11
Headwater Habitat Evaluation						
Index substrate score	13.0	8.0	16.0	19.0	24.0	25.0
Embeddedness (1 to 5)	3.17	1.67	2.00	3.50	4.67	4.67
95% confidence intervals	1.27-5.07	0.24-3.10	0.76-3.24	2.26-4.74	3.24-6.10	3.24-6.11
Riparian width (meters)	59	2.25	0	12	102	59
Dissolved oxygen (mg/l)	5.33	6.35	11.63	10.77	10.53	7.57
95% confidence intervals	0-26.55					0-39.97
Forest cover (ratio)	0.094	0.094	0.048	0.046	0.016	0.138
Maximum pool depth (cm)	8.0	20.0	22.0	36.0	18.0	36.5
Floodplain quality score	20	14	12	12	20	11
Log gradient (meters / km)	0.258	0.281	0.305	0.288	0.343	0.333
Silt and muck (ratio)	0.420	0.665	0.455	0.225	0.050	0.050
Temperature (^{o} Celsius)	18.67	16.07	20.8	16.35	13.19	16.58
95% confidence intervals	8.76-28.58	0-50.76	6.87-39.93	8.88-23.8	7.32-19.1	4.70-28.5
Open canopy (ratio)	0.039	0.983	0.955	0.167	0.071	0.067
95% confidence intervals	0.02-0.06	0.91-1.0	0.84-1.0	0-0.59	0-0.19	0.05-0.08
Total suspended solids (mg/l)	44.29	37.78	35.00	35.00	38.57	38.57
Total phosphorus (mg/l)	0.350	0.110	0.125	0.125	0.100	0.100
Log total Kjeldahl nitrogen (mg/l)	-0.140	-0.502	-0.387	-0.387	-0.398	-0.398
Cropland (ratio)	0.511	0.927	0.687	0.662	0.908	0.692
Total ammonia (mg/l)	0.195	0.155	0.275	0.275	0.110	0.125
Residential area (presence/absence)	1	0	1	1	0	0
Log conductivity (micromhos/cm)	3.070	2.757	2.563	2.580	2.422	2.607
95% confidence intervals		2.08-3.43	1.79-3.34	1.66-3.50	2.31-2.53	2.57-2.65
Log turbidity (Nephelometric Turbidity Units - NTU)	1.260	1.668	2.737	1.182	1.811	1.281
95% confidence intervals	0-5.799	0.212-3.124	0-5.742	0-3.210	0-5.573	0-5.109

Table 2.8. Summary data for selected environmental variables (physicochemical and land use parameters) from Primary Headwater Habitat non-reference sites sampled in north-central Ohio from spring to fall of 2004-05.

	Correlation (R)	
Environmental Metric	HMFEI	HHEI
Headwater Habitat Evaluation Index substrate score	0.445	0.902
Embeddedness (low)	0.385	0.541
Riparian width (meters)	0.658	0.252
Dissolved oxygen (milligrams/liter)	0.298	0.561
Forest cover (ratio)	0.571	0.201
Maximum pool depth (centimeters)	0.303	0.448
Floodplain quality score	0.435	0.213
Log gradient	0.378	-0.175
Silt and muck (ratio)	-0.630	-0.608
Temperature (Celsius)	-0.676	-0.309
Open canopy (ratio)	-0.436	-0.398
Total suspended solids	-0.642	-0.430
Total phosphorus	-0.560	-0.455
Log total Kjeldahl nitrogen	-0.750	-0.178
Cropland (ratio)	-0.444	-0.428
Total ammonia (milligrams/liter)	-0.525	-0.346
Residential area (presence/absence)	-0.436	0.232
Log conductivity (micromhos/centimeter)	-0.451	-0.145
Log turbidity	-0.333	-0.225

Table 2.9. Correlations of data from 19 selected environmental variables (physicochemical and land use parameters) with Headwater Macroinvertebrate Field Evaluation Index (HMFEI) and Headwater Habitat Evaluation Index (HHEI) from Primary Headwater Habitat sites sampled in Ohio from spring to fall of 2004-05.

Ordination and Distance Matrix Analyses

Detrended canonical correspondence analysis (DCCA) was run with stream segments as with no transformations or down weighting (Leps and Smilauer 2003, ter Braack and Smilauer 2002). The first eigenvalue was 0.742 with the first gradient the longest, and the gradient length equaled 3.843. This value was less than 4 (and also due to normalized data), therefore a Redundancy Analysis (RDA) was run. The RDA was run with the invertebrate metrics merged with the invertebrate data with sample sites compared against the 19 environmental variables (physicochemical and land use data) (Table 2.10, Figure 2.2). In the reduced model a Monte Carlo permutation test (*n*=499) was

Axes	1	2	3	4
Eigenvalues	0.136	0.102	0.1	0.088
Species-environment correlations:	1	0.994	0.998	0.992
Cumulative percentage variance				
of species data:	13.6	23.8	33.9	42.6
of species-environment relation:	14.2	24.9	35.3	44.5

Table 2.10. Summary of Redundancy Analysis of selected Primary Headwater Habitat sample site invertebrate data with 50 possible invertebrate metrics merged with invertebrate taxa data constrained against 19 environmental variables (physicochemical and land use data) from Primary Headwater Habitat site data from Ohio sampled in spring to fall 2004-05 for invertebrate community index development. The possible invertebrate metrics were passive to determine their orientation related to the invertebrate taxa data.

conducted on the final RDA results (Table 2.10). The eigenvalue for the test of significance for the first canonical axis equaled 0.136 with an F-ratio of 0.157 and *P*-value of 0.230. The test of significance for all canonical axes was 0.958 with an F-ratio of 1.194 and a *P*- value of 0.290.

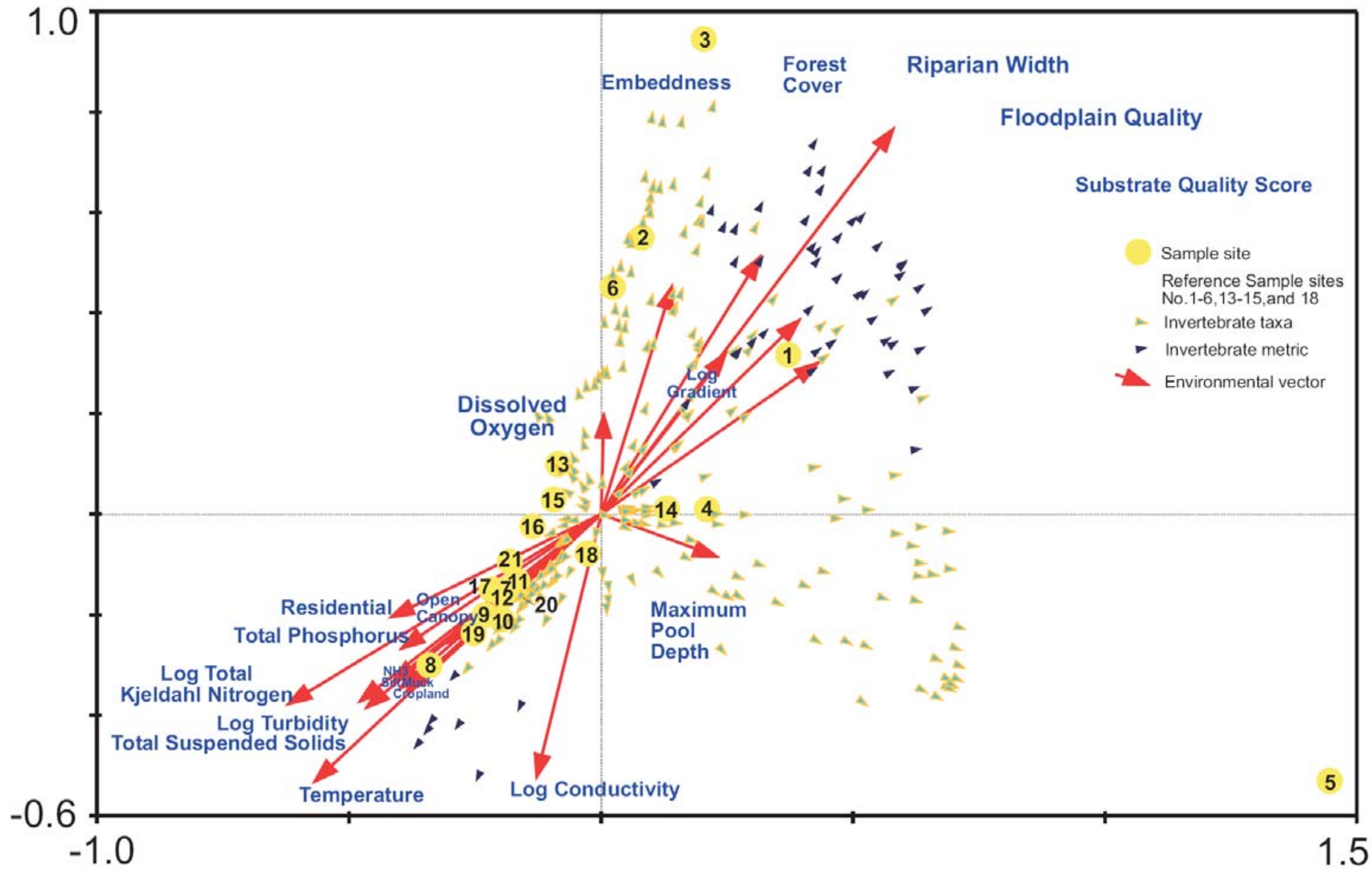

Figure 2.2. Redundancy Analysis Triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for 21 selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

Species Ordination of Invertebrate Communities

Taxa sensitivity was oriented and related to positive or negative environmental vectors (and sample sites) (Figure 2.2). The positive environmental variables, reference sample sites, and primarily sensitive taxa were positioned and related to each other in the upper left, upper right, and lower right quadrant. Negative environmental vectors, disturbed sites, and tolerant invertebrate taxa were located in the lower left quadrant related negatively to water resource quality (Figure 2.2).

Most facultative organisms generally were grouped near the center and just below the center in the upper lower left quadrant toward the disturbed sites of moderate community quality and diversity (sites 21,11,17,7,12,and 20) (Figure 2.2). Common facultative taxa in this area consisted of the mayfly *Stenacron* sp. (near center), the riffle beetle *Stenelmis* sp., *Orconectes* sp. crayfish, calopterygid damselflies, and the dipterans *Helius* sp. and *Tipula* sp. Other facultative taxa located in this area of the ordination plot were the caddisflies, *Hydroptila* sp. and *Cheumatopsyche* sp., and the common midges, *Dicrotendipes neomodestus* and *Hayesomyia/Thienemannimyia* sp. (Figure 2.2).

Tolerant taxa were grouped toward the lower quality sites (numbers 8, 9, 10, and 19) and the negative environmental vectors in the lower left quadrant of the ordination) (Figure 2.2). Representative tolerant invertebrate taxa grouped with lower quality communities were the snail *Physella* sp., leeches (Glossiphoniidae), and Turbellaria (1801) (Figure 2.2). Other associated tolerant taxa included were oligochaete worms, the beetle *Haliplus* sp., and the planorbid snail, *Planorbella pilsbryi*.

Final Invertebrate Metrics Analyses

Euclidean distances were calculated between biplot metric scores, and the cluster analysis determined what taxa were "near" each other and "near" which metrics. Final invertebrate metric selections were made from the hierarchical clusters formed from the Euclidean distance matrices (PCORD) from RDA metric invertebrate biplot scores of invertebrate and species data compared to environmental and sample site data (CANOCO) (Table 2.11, Figure 2.3) (Leps and Smilauer 2003, ter Braack and Smilauer 2002, Quinn and Keogh 2002). The invertebrate metrics listed below were grouped into nine clusters when I bisected a line across the dendrogram where hierarchical clustering results still retained >88 percent of the distance information (Table 2.11).

Invertebrate Metric	Full Metric Name	Hierarchical Invertebrate Cluster No.
HMFEITOT	Total Headwater Macroinvertebrate Field Evaluation Index	1
NTTEPTTX	Number (No.) Total EPT Taxa	1
NSENTXQQ	No. Sensitive Taxa (Quant. +Qual.)	1
LNMITTXQQ	Log No. Midge Taxa (Quant. +Qual.)	1
LNSMTXQQ	Log No. Sensitive Midge Taxa (Quant. + Qual.)	1
NOQTTTX	Total No. Quantitative Taxa (Quant. + Qual.)	1
NSNMTXQQ	No. Sensitive Midge Taxa (Quant. + Qual.)	1
TNTXQTQL	Total No. Taxa (Quant. + Qual.)	1
NMTXQLQT	No. Midge Taxa (Quant. + Qual.)	1
NPRDTXQQ	No. Predator Taxa (Quant. + Qual.)	1

continued

Table 2.11 (continued)

Invertebrate Metric	Full Metric Name	Hierarchical Invertebrate Cluster No.
NOQLTX	No. Qualitative Taxa (Total)	2
TCSEPTX	Total Count Sensitive EPT Taxa (Quant. Count)	2
SRTCSEPT	Square Root (Total Count Sensitive EPT Taxa)	2
QLMAYTX	No. Mayfly Taxa in Qualitative Sample	2
NOQTCWTX	No. Coldwater Taxa in Quantitative Sample (Individual Type)	3
TNCWTXQQ	Total No. Coldwater Taxa (Quant. + Qual.)	3
NCADTXQQ	Total No. Caddisfly Taxa (Quant. + Qual.)	3
NCWMITQQ	Total No. Coldwater Midge Taxa (Quant. + Qual.)	3
QTPCWTX	Percent Coldwater Taxa of Total Quant. Taxa (Individual Type)	3
NSNT2NFT	No. Sensitive Taxa / No. Facultative Taxa (Quant. + Qual.)	3
QQST2FAT	No. Sensitive Taxa / (No. Facultative + Tolerant Taxa) (Quant. + Qual.)	3
LTCTCWCD	Log (Total Count Coldwater Caddisflies) (Quant.)	3
PNSTXOQQ	Percent No. Sensitive Taxa of Total No. Taxa (Quant. + Qual.)	3
LCTSCDQT	Log (Total Count Sensitive Caddisflies in Quant. Sample)	3
PCWTXOTC	Percent Coldwater Taxa of Total Count	4
NSTNTXQQ	Total No. Stonefly Taxa (Quant. + Qual.)	4
TSEPTXQQ	Total No. Sensitive EPT Taxa (Quant. + Qual.)	5
PSNTXOTC	Percent Sensitive Taxa of Total Count	5
STCST2FT	Sq. Rt.(Total Count Sens. Taxa / Total Ct. (Facultative + Tolerant Taxa)	5
TCSNT2FT	Total Count Sensitive Taxa / Total Count Facultative Taxa	5
TCST2FAT	Total Count Sensitive Taxa / Total Count (Facultative + Tolerant Taxa)	5
NMAYTXQQ	Total No. Mayfly Taxa (Quant. + Qual.)	6
NSENMYQQ	Total No. Sensitive Mayfly Taxa (Quant. + Qual.)	6
NITXQLQT	Total No. Intolerant Taxa (Quant. + Qual.)	6
LTOTCTST	Log (Total Count Stoneflies) (Quant.)	6
LTCSHSTN	Log (Total Count Shredder Stoneflies) (Quant.)	6
LTCST2TT	Log (Total Count Sensitive Taxa / Total Count Tolerant Taxa) (Quant.)	6
PSENMYQT	Percent Sensitive Mayflies in Quantitative Total Count	7
PSEPTOTT	Percent Sensitive EPT of Quantitative Totals	7
APSEPTOT	Arcsine Sq. Rt. (Percent Sensitive EPT of Quant. Totals)	7
APINTOTS	Arcsine Sq. Rt. (Percent Intolerant Taxa of Total Sensitive Taxa) (Ct.)	7
RSH2NSSH	Sq. Rt. (Sensitive Shredders / Non Sensitive Shredders)	8
SSH2NSSH	Sensitive Shredders / Non Sensitive Shredders	8
PTLTONQT	Percent Tolerant Taxa of Total Tolerant Individual Taxa in Quant. only	9
PTLTOTQQ	Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quant. + Qual.)	9

continued

Table 2.11 (continued)

Invertebrate Metric	Full Metric Name	Hierarchical Invertebrate Cluster No.
PTOLOTCT	Percent Tolerant Taxa of Total Count	9
PNSGCOGC	Percent No. Sensitive Gatherer Collectors (GC) of Total GC Count	9
PFTOQQTX	Percent FacultativeTaxa of Total Taxa (Quant. + Qual.)	9
APTMTOMT	Arcsine Sq. Rt.(Percent Tol. Midge Taxa of Total Midge Taxa (Quant. + Qual.)	9
TCTTOLMI	Total Count Tolerant Midges	9

Table 2.11. List of final 50 possible invertebrate metrics from Hierarchical cluster analysis listed by clusters from a Euclidean Distance Matrix (Wards Method) using PCORD from Redundancy Analysis of metric biplot scores and invertebrate data with site scores and environmental data (CANOCO) from Primary Headwater Habitat site data from Ohio sampled sites in spring to fall 2004-05 for invertebrate community index development. Nine clusters formed when line bisected the dendrogram where hierarchical clustering results still retained >88 percent of the distance matrix information. Abbreviations were as follows: No. = number; Quant. = quantitative data; Qual. = qualitative data; EPT = Ephemeroptera /Plecoptera / Trichoptera; Sens. = sensitive; Sq. Rt. = square root; Ct. = count; Tol. = tolerant; and GC = gatherer collector

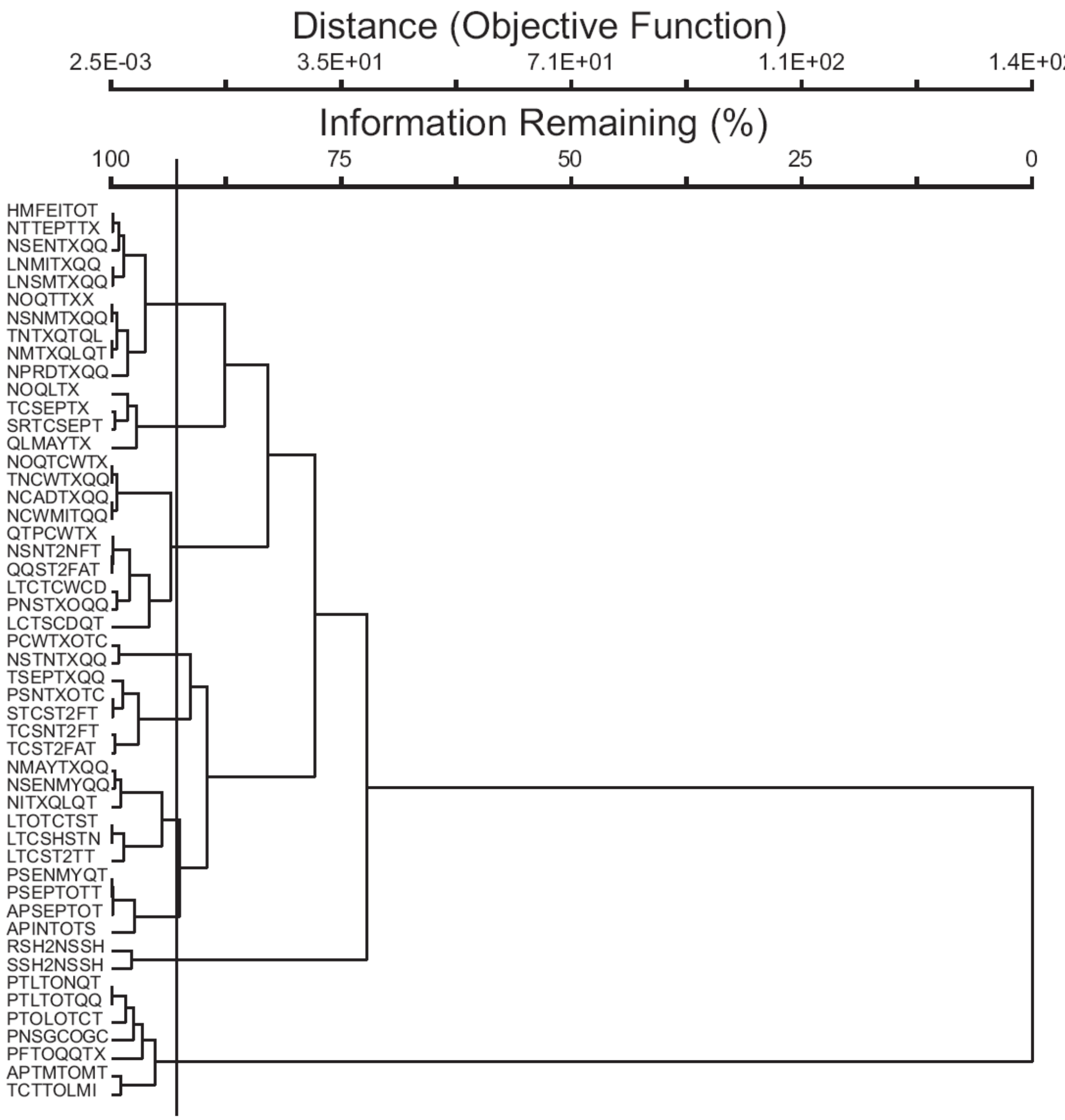

Figure 2.3. Dendrogram of hierarchical cluster analysis of final 50 possible invertebrate metrics from Euclidean Distance Matrix (Wards Method) using PCORD from Redundancy Analysis of metric biplot scores and invertebrate data with and environmental data and site scores (CANOCO) from Primary Headwater Habitat site data from Ohio sampled sites in spring to fall 2004-05 for invertebrate community index development. Nine clusters formed when line bisected the dendrogram where hierarchical clustering results still retained >88 percent of the distance matrix information.

DISCUSSION

Quantitative Sampling Methods Comparison

The artificial leaf pack Colonizer took approximately 2 hours more to process into the no. 30 screen and no. 40 screen collection jars compared to bucket and Surber samples. The leaf pack colonizer method also required two trips to the site, whereas the bucket and Surber samples were collected in one trip. This was significant in regard to shrinking monitoring resource dollars at the local, county, state, and federal levels.

Through various comparative and statistical analyses of the quantitative macroinvertebrate data from the quantitative sample methods comparison, the bucket method seems to give the best possible opportunity for the highest diversity and most complete quantitative macroinvertebrate data collection in these PHWH streams. Analysis of quantitative data from the six selected PHWH sample sites determined that the USEPA Bucket sample method data was best of those three compared methods and was used for the PHWH quantitative data analyses for PHWH index development.

Associations of Macroinvertebrates and the Environment

In the RDA ordination the relationship and orientation of facultative or tolerant taxa with the disturbed sites and toward the negative environmental vectors indicated changes to community quality and structure from the reference condition (Yoder and Rankin 1998) (Figure 2.2, Table A.1). Decreased habitat niches from construction sedimentation or suburbanization at sites 16 (C6), 17 (C8), and 19 (C3) lowered diversity and quality (decreased EPT taxa totals) compared to local reference site 18 (C7) (Figure 2.2, Table A.1). Trophic changes occurred, like increased number of isopods (Asellidae) and Turbellaria that replaced sensitive shredders and scrapers. Decreases in physical stream habitat quality, even temporary conditions such as at site 16 (C6), caused invertebrate community species diversity to decrease. Gorman and Karr (1978) reported similar relationships within fish communities in impacted streams. However, impacts to sites 17 (C8) and 19 (C3) were chemical, nutrient, sediment, and flow alteration disturbances from urbanization further upstream from the sampled stream reaches. The decreased sensitive taxa and increased facultative and tolerant taxa caused by permanent land use changes in the upper watershed indicated the importance of riparian stability and width (Karr and Schlosser 1978, Resh et al. 1988, Wallace et al. 1986).

Nutrient enrichment inputs changed the invertebrate community structure at site 10 (NC8), as agricultural inputs affected invertebrate community quality (Roth et al. 1996). The shredder community consisted primarily of tolerant beetles, *Peltodytes* sp. and *Berosus* sp., and a tolerant midge *Cricotopus bicinctus* with abundance algae under an open canopy. Scrapers were dominated by tolerant snails: *Physella* sp., *Menetus dilatatus*, and *Planorbella pilsbryi* (Figure 2.2). Over 2000 oligochaete worms were the predominant gatherer collector taxa. Community diversity at intermediate quality sites, like site 11 (NC10) which received some nutrient inputs, consisted of a combination of sensitive, facultative, and tolerant taxa at lower ratios as would have been predicted.

These species – environment relationships allowed invertebrate metrics to capture changes to community composition from a reference condition. Thus, invertebrate metrics were analyzed to develop an invertebrate community index.

Final Macroinvertebrate Metric Selections

Invertebrate metric cluster No. 1 consisted of high diversity taxa totals or totals of different sensitive groups. Possible metrics in cluster no. 1 included general metrics like Total HMFEI, No. Total EPT Taxa, and Total No. Sens. Taxa (Quant./Qual.). The metrics were grouped between important positive environmental vectors: Riparian Width, Floodplain Quality, and HHEI Substrate Score (Figure 2.4 – portion of Figure 2.2).

The total HMFEI metric was not kept, because it was developed as an index. The metric, number of total EPT taxa (NTTEPTX), was not selected. There was more diversity and sensitivity information by looking at the mayfly

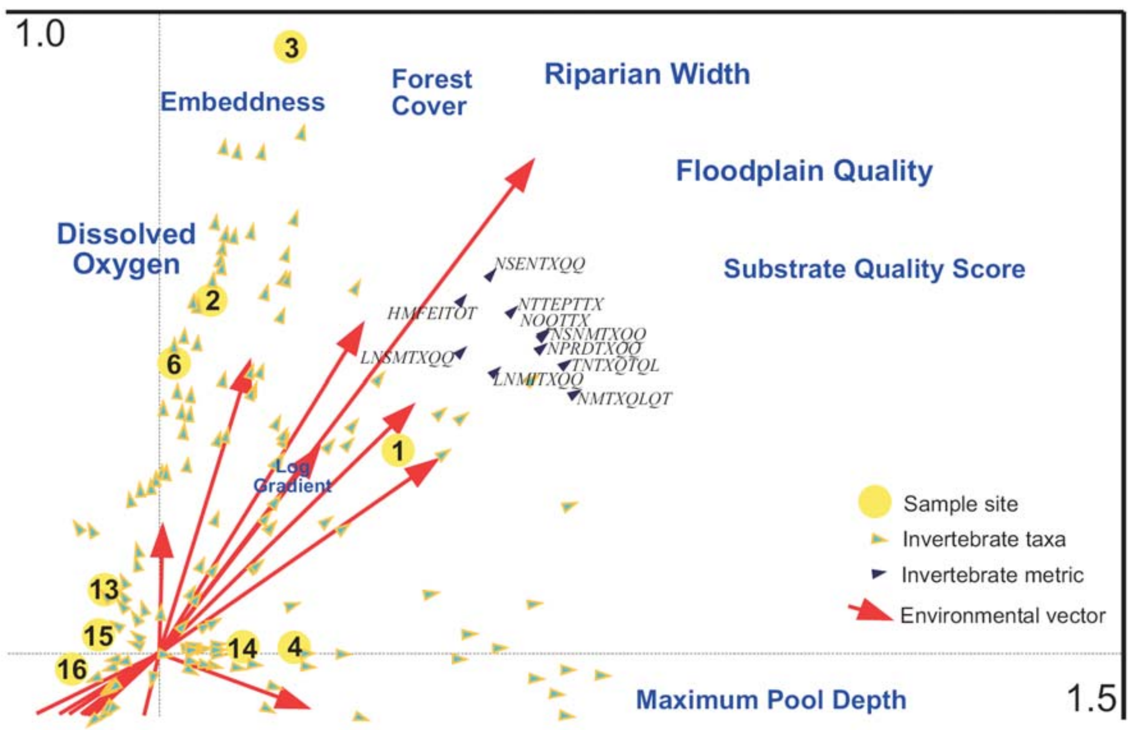

Figure 2.4. Invertebrate metric cluster 1 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

(Ephemeroptera), stonefly (Plecoptera), and caddisfly (Trichoptera) totals separately. All EPT metrics were equally correlated to increasing diversity and quality, like NTTEPTX.

The three midge diversity metrics in cluster 1 were not selected. The midge metrics listed were covered by the more global metrics of which they are a subset: (total no. sensitive taxa (quantitative (quant.) + qualitative (qual.) data) (NSENTXQQ) and total no. taxa (quant. + qual.) (TNTXQTQL). NMITXQLQT was redundant to TNTXQTQL (0.956), and both sensitive midge metrics (NSNMTQQ and its log equivalent) were redundant to both TNTXQTQL (0.967 and 0.825, respectively) and NSENTXQQ (0.929 and 0.888, respectively).

The metric, number of predator taxa (qual. + quant.), a trophic metric, was not kept for the ICI, because it was not as informative. Many predators in the PHWH streams were abundant facultative midges or dipterans besides perlid stoneflies. It was difficult to garner consistent and meaningful relationships. The separation or relationship of total predator taxa (for scoring) through the environmental condition gradient did not seem as distinct. Also, NPRDTXQQ was redundant with and covered by TNTXQTQL (r = 0.933).

One of two invertebrate metrics selected from the cluster 1 metrics was the number of sensitive taxa (quant. +.qual.) (NSENTXQQ) - an important component of PHWH streams, The NSENTXQQ metric, as it is more global in scope, would encompass and include other sensitive taxa diversity groups. The other invertebrate metric selected in cluster 1 was the total number of taxa (quant. + qual.) (TNTXQTQL). TNTXQTQL was more global and highly correlated to diversity and quality (r=0.838 to HMFEI tot). Data consistently indicated that the number of taxa increased from 14-81% of the time when the qualitative data was added. Therefore, TNTXQTQL was selected over the redundant companion diversity metric – number of total taxa (quantitative data only) (r= 0.992).

Invertebrate metric cluster 2 consisted of four metrics: total no. qualitative (qual.) taxa (NOQLTX), the no. qual. mayfly taxa (QLMAYTX), the total count sensitive EPT taxa (quant. count) (TCSEPTX) and its square root equivalent (SRTCSEPT). This cluster was grouped below cluster 1 toward the HHEI

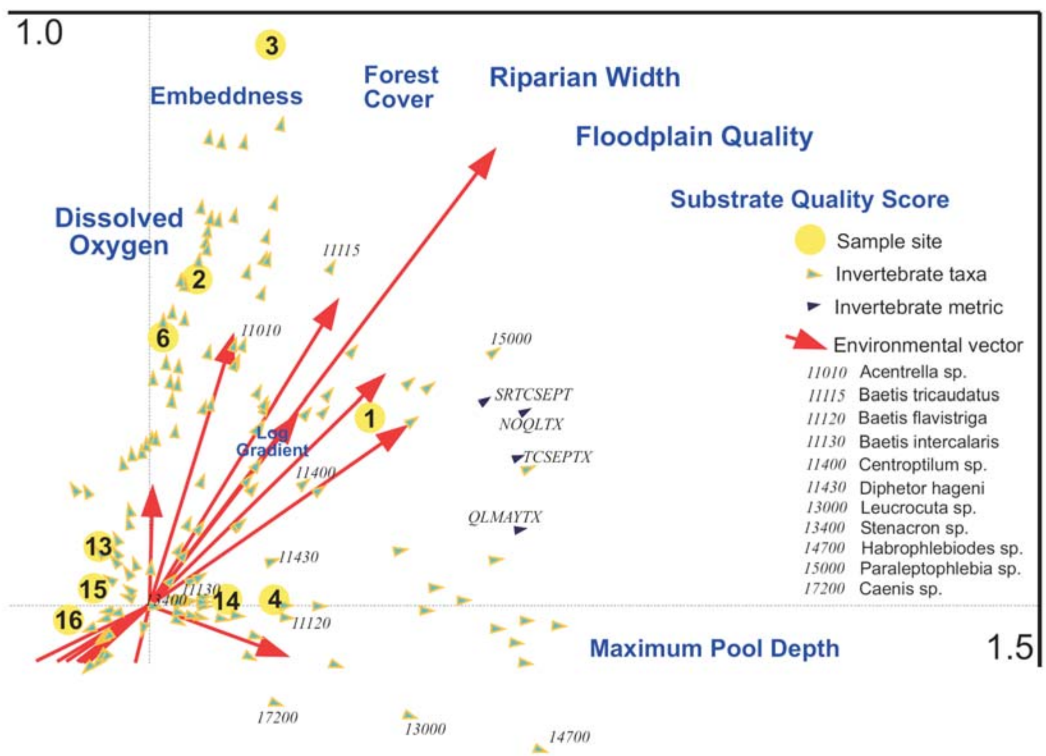

Figure 2.5. Invertebrate metric cluster 2 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

Substrate Score environmental vector and closer to Maximum Pool Depth (Figure 2.5). This group seemed to be more influenced by the pool species, qualitative collections (particularly not in the main channel), and the facultative taxa collected.

The sensitive EPT metrics, TCSEPTX and SRTCSEPT, were not kept, because sensitive metrics were covered by more global metrics in cluster 1 (NSENTXQQ – r= 0.83-0.85, respectively) and a more general count metric in cluster 5 not restricted to only EPT taxa (PSNTXOTC). Also, EPT taxa metrics were to be included individually, and the qualitative and quantitative EPT taxa totals can be readily determined by adding the individual order totals.

The invertebrate metric, QLMAYTX, was located lowest in the top right quadrant and more in the middle between the HHEI substrate score and maximum pool depth environmental vectors. QLMAYTX was median between:) some facultative mayflies (e.g., *Baetis flavistriga* (11120) and *Stenacron* sp. (13400) near sample site 14 and center); 2) some pool mayflies (like the facultative *Caenis* mayfly (17200) and sensitive *Paraleptophlebia* (15000) and *Leucrocuta* (13000) mayflies); and 3) sensitive mayflies located throughout both upper right and lower right quadrants (e.g., *Acentrella* sp. near low embeddedness vector, *Baetis tricaudatus* (near riparian width and forest cover environmental vectors), *Diphetor hageni* and margin baetid *Centroptilum* sp. toward the middle near the substrate score vector, and the heptageneid mayfly *Habrophlebiodes* sp. down toward sample site 5 and in line with maximum pool depth vector). The greater influence included facultative mayflies which were more ubiquitous and at more sites. The sensitive mayfly and percent mayfly metrics, though, were still centered in the metric cluster along the three central environmental vectors: floodplain quality, riparian width, and percent forest cover. However, the range for qual. mayfly taxa (QLMAYTX) (0-7) was less than half that of the metric no. mayfly taxa (quant. + qual.) (NMAYTXQQ). With 0-15 mayfly taxa, depending on sample site quality along the human condition gradient (Karr and Yoder 2004), there is greater stability, range, and robustness. The QLMAYTX invertebrate metric is more limited and was excluded by the more global invertebrate metric NMAYTXQQ discussed later in cluster 6.

The total number of qualitative taxa (NOQLTX) was selected even though it is a subset of TNTXQTQL (r = 0.88). It gives information for the whole qualitative sample, including encompassing all EPT and midge totals. The NOQLTX range of taxa at 4-46 is much higher than QLMAYTX (0–7), for example. Type I error from possible inefficient qualitative sampling would be reduced and less drastic using the NOQLTX compared to just the number of mayfly taxa collected in the qualitative sample (QLMAYTX). More importantly, the invertebrate metric, NOQLTX, can add robustness and increase diversity at a site with a monotonous riffle/run channel habitat (e.g., bedrock stream center channel) where the quantitative sample is collected. Habitat diversity in that reach would be toward the edges, so the NOQLTX metric could be close to equaling the quantitative taxa totals illustrating the “niche - restricting habitat diversity" in the main channel. Also a qualitative taxa total equal to or higher than the quantitative sample total could indicate an episodic toxic event in the channel from upstream. For these reasons the number of qualitative Taxa (NOQLTX) was selected as a final invertebrate metric.

Cluster 3 invertebrate metrics identified both distinctive features of PHWH stream systems: their abundant diversity of coldwater (CW) fauna and total numbers of sensitive taxa present. Cluster 3 invertebrate metrics were relationally positioned near the riparian width, forest cover, embeddedness, and related dissolved oxygen environmental vectors and reference sample sites 2, 3,

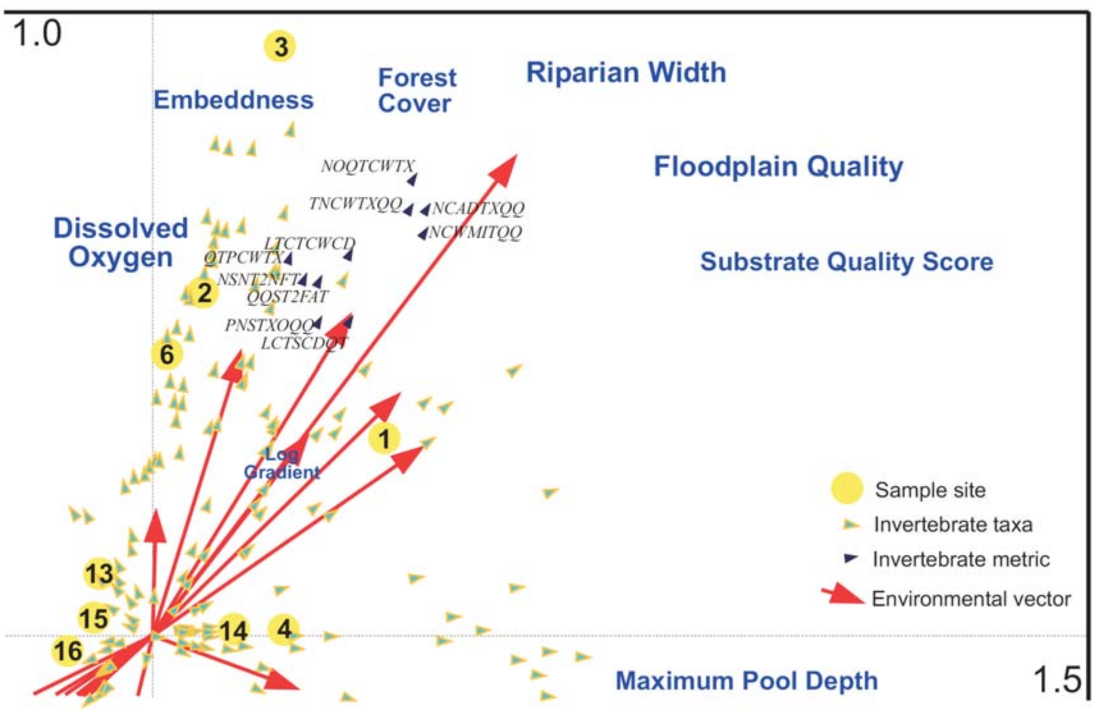

Figure 2.6. Invertebrate metric cluster 3 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

and 6 (Spring Brook, Alffelder Trib. to Silver Creek, and West Woods Trib. to Silver Creek, respectively) (Figure 2.6). Common PHWH community qualities between these sites were very high numbers of CW taxa (29-38), CW midges (15-18), and sensitive taxa (54-65).

In hierarchical cluster 3 the invertebrate metric, number of quantitative CW taxa (NOQTCWTX), was not selected and was redundant with the more general metrics, TNTXQTQL (r=0.863) (cluster 1) and total no. CW taxa (quant. + qual.) (TNCWTXQQ) (r=0.996). The more global (covers all CW taxa) TNCWTXQQ was kept as a final invertebrate metric. Log (total count CW caddisflies) (LTCTCWCAD) was not retained. The information would be garnered from the total CW and caddisfly metrics (TNCWTXQQ and NCADTXQQ in this cluster group) and the percent CW taxa metric, PCWTXOTC, in cluster 4.

The metric, number of CW midge taxa (quant. + qual.) (NCWMITQQ), was kept as a final invertebrate metric over NMTXQLQT and NSNMTXQQ (and its Log) from cluster 1. The CW midge fauna found in these PHWH stream systems was very unique and constituted a very large proportion of the total biological community. Some are facultative (likely referring to their trophic function), but they count positively in this CW invertebrate metric. The range of CW midges collected at the reference sample sites was sufficient for good scoring ranges (0 to 18 midges). Decreases in CW midge taxa diversity related at some sample sites to decreased forest cover, groundwater recharge, and water temperature increases with less dissolved oxygen. The correlation to HMFEI and total HMFEI indicated (r=0.754 and 0.804, respectively) a consistent response to negative impacts.

There were three general sensitive invertebrate metrics grouped in cluster 3. Percent no. sensitive taxa of total no. taxa (quant. + qual.) (PNSTXOQQ) was a good metric but not kept. There was a better sensitive percent metric in cluster 5 – PSNTXOTC – that was more global. PSNTXOTC gave more information using total count data than diversity totals in PNSTXOQQ (also r= 0.831). In cluster 3 there were two ratios: no. sensitive taxa / no. facultative taxa (NSNT2NFT) and no. sensitive taxa / no. facultative and tolerant taxa (QQST2FAT). NSNT2NFT was not selected, because there was a similar ratio metric in cluster 5 that gave more information. It was like the other ratio in this cluster group (QQST2FAT), but TCST2FAT used more informative total count data instead of just the individual taxa totals from the quantitative and qualitative taxa.

Three caddisfly metrics were grouped in cluster 3: one sensitive, one coldwater, and one more global, respectively. The log (total count CW caddisflies) (LTCTCWCAD) and the log (count sensitive caddisflies in quantitative sample) (LCTSCDQT) were redundant data subsets and covered by the more general caddisfly metric, total no. caddisfly taxa (NCADTXQQ) (r=0.854 and 0.828, respectively) and part of other sensitive and CW percent count metrics discussed later (clusters 4 and 5). NCADTXQQ was one of the basic invertebrate metrics that was a portion of the EPT taxa information. Total no. caddisfly taxa (NCADTXQQ) was selected from cluster 3 as a final invertebrate metric.

Both invertebrate metrics in cluster 4 were selected as final invertebrate metrics for the ICI: percent CW taxa of total count (PCWTXOTC) and total no. stonefly taxa (quant. + qual.) (NSTNTXQQ). PCWTXOTC is located close to end of floodplain quality vector with NSTNTXQQ located between floodplain quality and HHEI substrate score (Figure 2.7). PCWTXOTC was close spatially and in

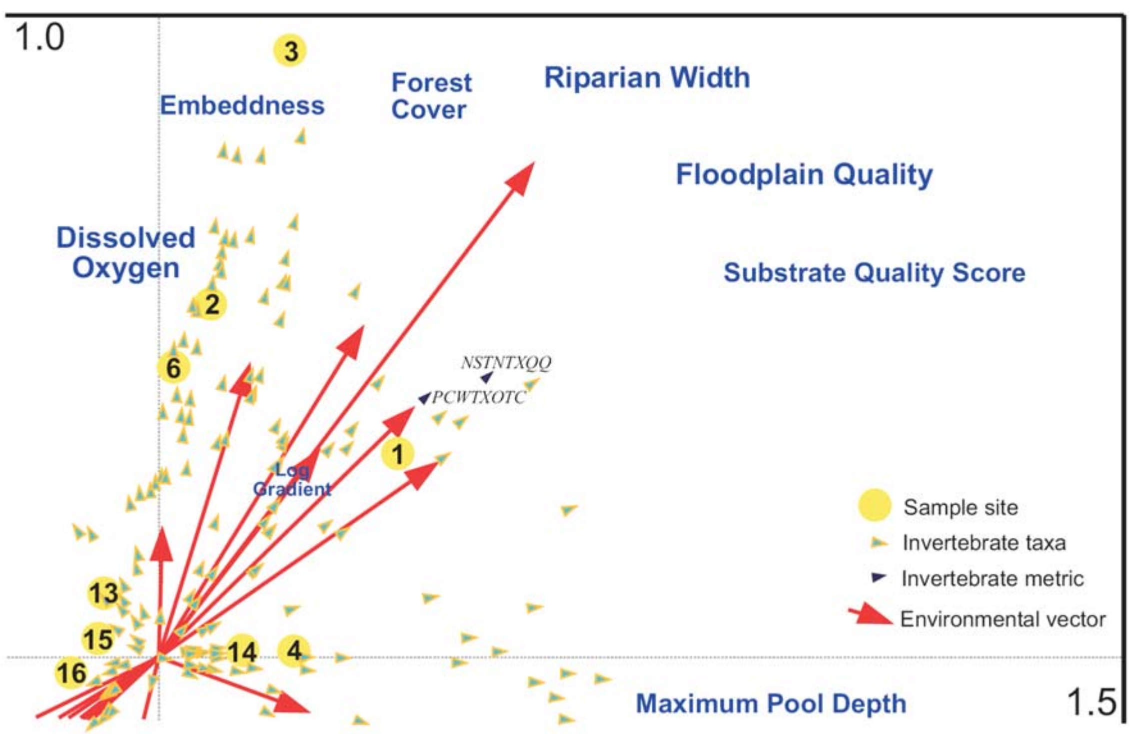

Figure 2.7. Invertebrate metric cluster 4 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

content to QTPCWTX in cluster 3 (redundant - r=0.987), but the total count data (PCWTXOTC) gave more density information. Percent total count data showed predominance by one taxa or a general decrease across all of the CW taxa present depending on the impact depending on sample site.

NSTNTXQQ was a basic invertebrate metric that was a portion of the EPT taxa information. Stoneflies were a significant portion of the shredder trophic group in PHWH streams. Other stoneflies were predators and increased overall Plecoptera diversity. NSTNTXQQ was selected as a final invertebrate metric.

Invertebrate metric cluster 5 consisted of sensitive metrics: one diversity count, one percent sensitive metric, and three ratios. The group was in the center of the positive invertebrate metric cluster adjacent the riparian width environmental vector (Figure 2.8). Total count sensitive taxa / total count facultative taxa (TCSNT2FT) and its square root equivalent (STCST2FT), were not kept. The selected invertebrate metric ratio, total count sensitive / total count (facultative and tolerant taxa) (TCST2FAT), gave more ecological information (more informative in indicating nutrient enrichment, toxicity, or eroding quality conditions with information from two different groups – trophic and tolerant groups). Correlation to total HMFEI was 0.80 and indicated responsiveness to diversity and also changes from negative impacts. The combined facultative and tolerant taxa totals were also more practical compared to only facultative taxa in this ratio. If some facultative or tolerant taxa switched tolerance categories, due

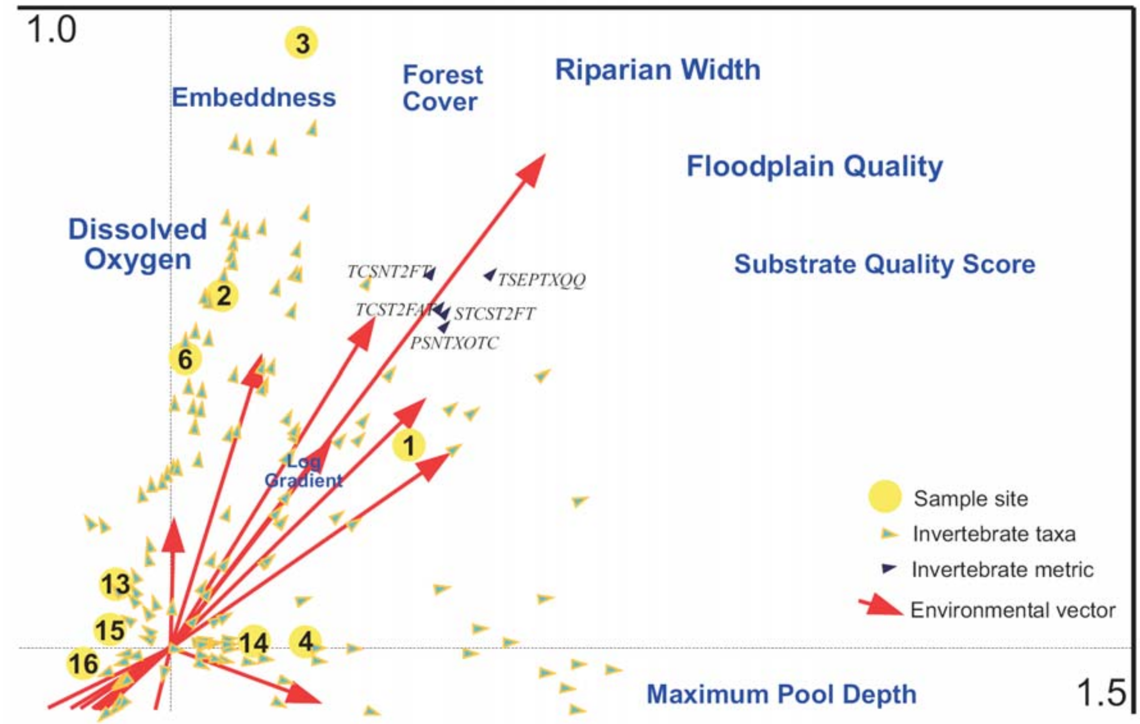

Figure 2.8. Invertebrate metric cluster 5 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

to newer increased ecological information, the ratio remains unaffected. Combined with a percent tolerant metric (cluster 9), this ratio measuring community composition quality was very informative in indicating nutrient enrichment, toxicity, or eroding quality conditions.

The invertebrate metric, percent sensitive taxa of total count (PSNTXOTC) in cluster 5 monitored a most important component of PHWH streams: sensitive taxa community composition. Decreases in PSNTXOTC indicated, in most cases, some negative impact to the PHWH biotic community. Looking at which species decreased or was eliminated usually pointed toward a certain type of negative impact or input. The total no. of sensitive EPT taxa (quant. + qual.) (TSEPTXQQ) was eliminated, because both selected sensitive invertebrate metrics, NSENTXQQ (cluster 1) and PSNTXOTC, were more global in nature and included the total sensitive EPT taxa as a subset. Correlations of NSENTXQQ (cluster 1) and PSNTXOTC showed TSEPTXQQ was redundant (r=0.909 and 0.889, respectively).

The six invertebrate metrics grouped in cluster 6 were located between clusters 1, 2, and 4 near the environmental vector ends of floodplain quality and HHEI substrate score (Figure 2.9). Invertebrate metrics in cluster 6 included four sensitive metrics (NMAYTXQQ, NSENMYQQ, NITXQLQT, and LTCST2TT) and two stonefly metrics (LTOTCTST and LTCSHSTN). The no. sensitive mayfly taxa (quant. + qual.) (NSENMYQQ) was located toward the left in cluster 6 above the floodplain quality vector and was influenced by sensitive mayflies to the left. The no. mayfly taxa (quant. + qual.) (NMAYTXQQ) was farthest right in cluster 6 equally between NSENMYQQ and QLMAYTX (cluster 2) and influenced by the qualitative mayflies collected. The final selected invertebrate metric, NMAYTXQQ, was the more global mayfly metric and measured Ephemeroptera diversity - an integral part of EPT taxa and a key invertebrate community component. NSENMYQQ was a subset of NMAYTXQQ (redundant with r= 0.8) and not kept. The no. of intolerant taxa (quant. + qual.) (NITXQLQT) was not selected. NITXQLQT was redundant with NSENTXQQ (r=0.882) which was more global and encompassed more total taxa and site quality range differentiation. Other selected invertebrate metrics also had enough range to differentiate between the highest quality sites. The excluded ratio, log (total count sensitive taxa / total tolerant taxa) (LTCST2TT), was similar to the previously selected TCST2FAT (r= 0.717). However, LTCST2TT did not include the facultative taxa totals, as TCST2FAT from cluster 5 did. The metric, log (total count stoneflies) (LTOTCTST), was not kept for the final invertebrate metric list, as the more global metric, NSTNTXQQ (from cluster 5), was already retained as

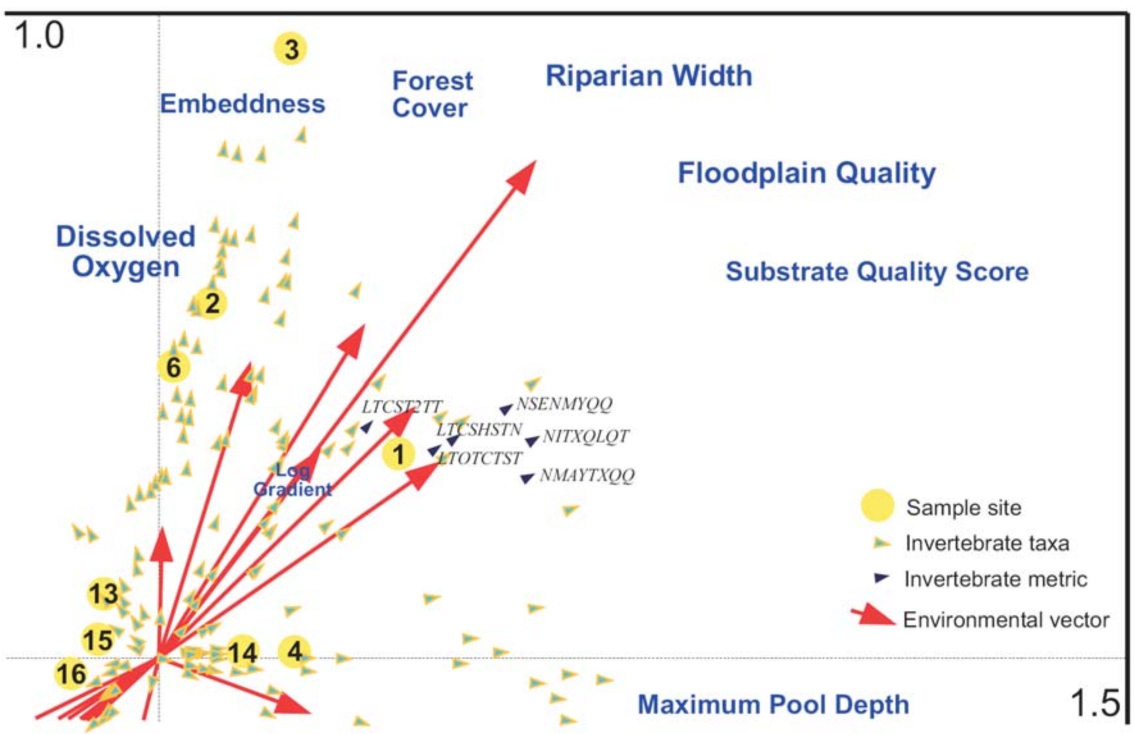

Figure 2.9. Invertebrate metric cluster 6 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

a final invertebrate metric. LTOTCTST, a subset of NSTNTXQQ, was redundant with NSTNTXQQ (r=0.794). The log (total count shredder stoneflies) (LTCSHSTN) was considered, but the shredder stonefly numbers varied over the growing season (Santiago 2007). The shredders were utilized in cluster 8 in a ratio to eliminate concentration changes in relation to availability of detritus through the growing season.

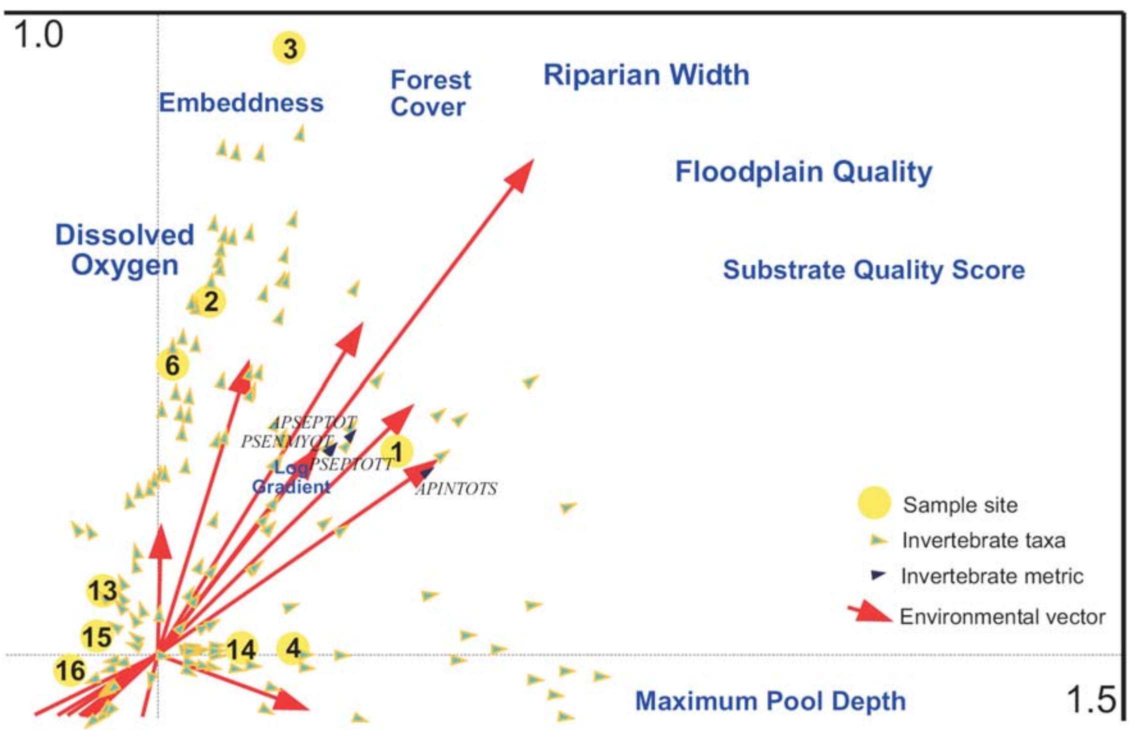

Figure 2.10. Invertebrate metric cluster 7 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

The four cluster 7 invertebrate metrics were all located along the log gradient and riparian width environmental vectors (Figure 2.10). Percent sensitive EPT taxa of total taxa (PSEPTOTT) and its redundant Arcsine square root (percent sensitive EPT taxa of total taxa) (APSEPTOT) were included in the more general selected metric, percent sensitive taxa of total count (PSNTXOTC), from cluster 5. Both metrics were less informative and redundant with PSNTXOTC (r =0.852 and 0.815, respectively).The metric, percent sensitive mayflies in quantitative total count (PSENMYQT), was very important to monitoring changes in what could be the most sensitive EPT taxa group – the order Ephemeroptera. Mayflies can be quickly affected by various impacts, like AMD-related inputs (as measured by low pH and high conductivity, TDS, and/or TSS) for example (Mount et al. 1997). Decreased mayfly diversity was caused by siltation/sedimentation or chemical /nutrient inputs from agricultural inputs, urbanization, and road ice treatment and/or construction at various sample sites. PSENMYQT was selected over the metric, Arcsine square root (percent intolerant taxa of total sensitive individuals) (APINTOTS), as the sensitive measures and ecological information from PSNTXOTC (cluster 5) and PSENMYQT was greater. PSENMYQT showed differences in the mayfly percentages at different range of condition sites and contributed to finding causes and/or sources of impacts based on which family group was affected and at what level of sensitivity the mayflies were affected. So distinguishing changes in the mayfly community composition was and is an important fingerprint of the PHWH macroinvertebrate community quality.

Invertebrate Metric cluster 8 contained two trophic ratios with shredders and was located centrally between the species on the riparian width and the HHEI substrate score environmental vectors toward the bases (Figure 2.11). The shredder community information was utilized by comparison of the sensitive to non-sensitive community taxa totals in a ratio to eliminate concentration (therefore percent) changes in relation to availability of detritus through the growing season. The ratio should not change significantly unless something

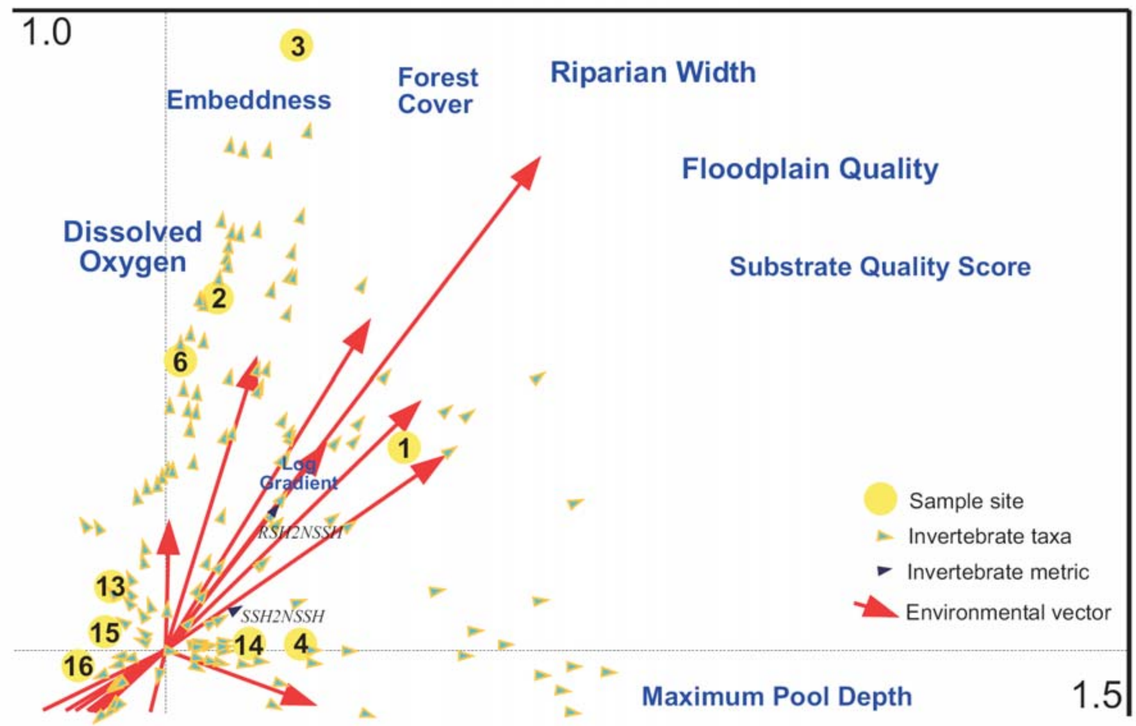

Figure 2.11. Invertebrate metric cluster 8 in upper quadrant of redundancy analysis triplot, a direct ordination of invertebrate taxa and physicochemical and environmental parameters for selected sites in Ohio sampled in spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development. Proposed invertebrate metrics were passive in ordination and were displayed to show relative position to the invertebrate taxa.

impacts the macroinvertebrate community to change the trophic community composition. The metric, total no. sensitive shredders / total no. non-sensitive shredders (SSH2NSSH) was selected over its square root equivalent (RSH2NSSH).

Invertebrate metric cluster 9 was located in the lower left quadrant near temperature, cropland, and log conductivity environmental vectors (Figure 2.2). These metrics in cluster 9 were negatively correlated and were associated with negative environmental variables (Figure 2.2). Percent tolerant taxa of total count (PTOLOTCT) was selected in this cluster. This metric indicated enrichment, recovery state, toxic conditions, or degradation depending on site data and impacts. PTOLOTCT was more global and redundant with PTLTONQT and PTLTOTQQ (r=0.927 and 0.920, respectively). The metric, percent number of sensitive gatherer-collectors of total gatherer-collectors (PNSGCOGC), contained less information than PTOLOTCT and was included in TCSNT2FAT (r= -0.818). Among non-sensitive gatherer-collectors were facultative CW midges, like *Micropsectra* sp., *Diamesa* sp., and *Zavrelimyia* sp., which were not negative features of a PHWH community, so PNSGCOGC was not kept. The other two unselected metrics, APTMTOMT and TCTOLMI, were included in PTOLOTCT and were redundant with it (r=0.779 and 0.866, respectively). Using PTOLOTCT, along with TCSNT2FAT, illuminated tolerant or facultative taxa and portrayed impacts that negatively dominated a PHWH macroinvertebrate community.

Ecological Coverage of Invertebrate Metrics

The final list of 14 selected PHWH ICI metrics (Table 2.12) adequately included a varied range of metrics compared to listed metric categories below (Table 2.13). I had previously divided the possible invertebrate metrics into these

Invertebrate Metric	Invertebrate Number	Simplified Metric Name	Invertebrate Cluster No.
TNTXQTQL	1	Total No. Taxa	1
NOQLTX	2	Total No. Qualitative Taxa	2
NMAYTXQQ	3	Total No. Mayfly Taxa	6
NSTNTXQQ	4	Total No. Stonefly Taxa	4
NCADTXQQ	5	Total No. Caddisfly Taxa	3
TNCWTXQQ	6	Total No. Coldwater Taxa	3
NCWMITQQ	7	Total No. Coldwater Midge Taxa	3
PCWTXOTC	8	Percent Coldwater Taxa of Total Count	4
NSENTXQQ	9	Total No. Sensitive Taxa	1
PSNTXOTC	10	Percent Sensitive Taxa of Total Count	5
PSENMYQT	11	Percent Sensitive Mayflies of Total Count	7
TCST2FAT	12	Total Count Sens. Taxa/(Facultative + Tolerant Taxa)	5
SSH2NSSH	13	Sensitive Shredders / Non-Sensitive Shredders	8
PTOLOTCT	14	Percent Tolerant Organisms of Total Count	9

Table 2.12. List of final selected Primary Headwater Habitat invertebrate metrics from Hierarchical cluster analysis from a Euclidean Distance Matrix (Wards Method) from Redundancy Analysis of invertebrate metric biplot scores and invertebrate data with site scores and environmental variables from Ohio sampled sites in spring to fall 2004-05 for invertebrate community index development.

metric group categories: general (total numbers of group) or ratios, sensitive, EPT, mayfly, caddisfly, stonefly, coldwater, midge, trophic (feeding guilds), tolerant, and facultative (ubiquitous and can increase totals in less than ideal conditions) groups. The Metric categories were all covered by at least one metric category listed in Table 2.13 below. More general categories were selected due to their global or more encompassing scope. Only the trophic metric category had less than two metrics associated with it, but shredders, gatherer-collectors, or scrapers could be discussed in relation to other group metric dynamics.

Metric Categories Metric	General or Ratios	Sensitive	EPT	Mayfly	Stonefly	Caddisfly	Coldwater	Midge	Trophic	Tolerant	Facultative
TNTXQTQL	X										
NOQLTX	X										
NMAYTXQQ			X	X							
NSTNTXQQ			X		X						
NCADTXQQ			X			X					
TNCWTXQQ							X				
NCWMITQQ							X	X			
PCWTXOTC	X						X				
NSENTXQQ		X									
PSNTXOTC	X	X									
PSENMYQT		X		X							
TCST2FAT	X	X								X	X
SSH2NSSH		X			X	X	X	X	X	X	X
PTOLOTCT	X									X	

Table 2.13. Selected macroinvertebrate metrics for Primary Headwater Habitat Invertebrate Community Index with indicated coverage of metric categories. EPT was abbreviation for Ephemeroptera / Plecoptera / Trichoptera.

Final Invertebrate Metrics Scoring

The final metric scatter plots against their respective drainage area sizes (0 – 2.59 km. ^{2}) did not show any significant correlation. The range of all correlation values (r) was low - between 0.0306 and 0.1654 (Fig. 2.12). The r^2 values were between 0.003 and 0.027 which were not statistically significant (r^2 < 0.423 (critical value) at alpha = 0.05 with 20 degrees of freedom) (Sokal and Rohlf 1973).

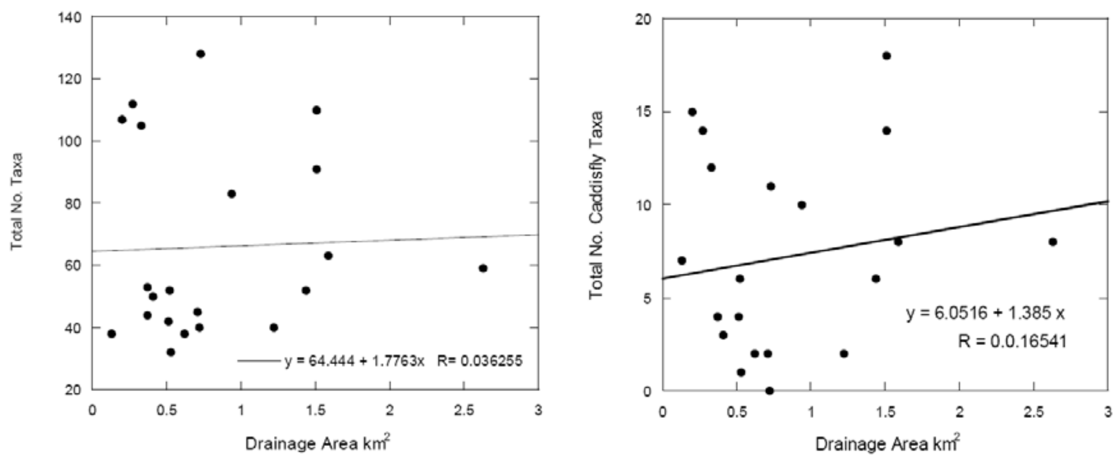

Figure 2.12. Scatter plots of representative metrics total number of taxa and number of caddisfly taxa (qualitative + quantitative data) that illustrated the lack of correlation to increased drainage area with line equations and correlation coefficients.

Each sample site data was graphed by distribution of the reference and range of condition sites which illustrated differences and responses to different impacts at the disturbed sites for each metric (Figures 2.13-2.19) (Mebane et al. 2003). The ranked frequency distribution curves illustrated responses through

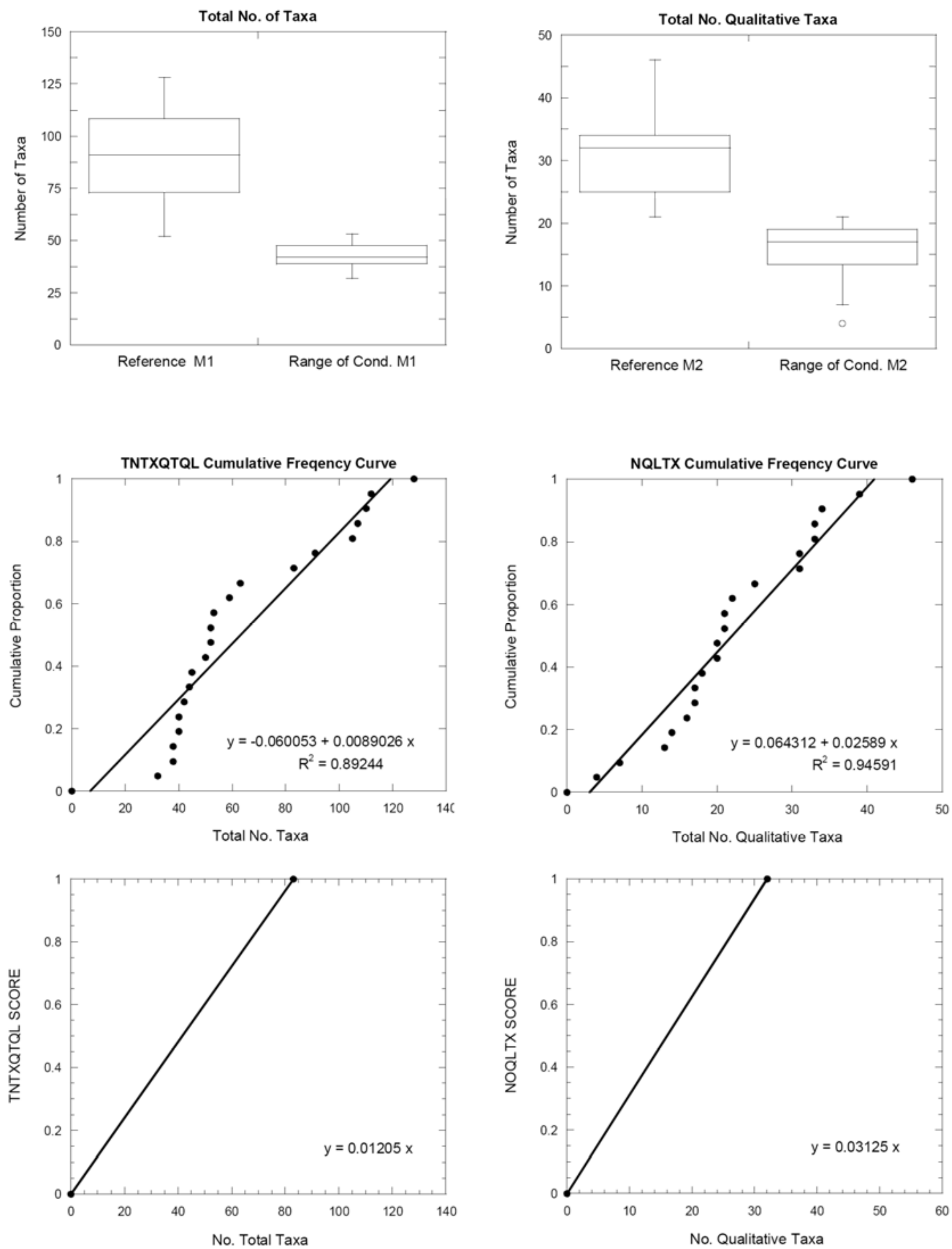

Figure 2.13. Distribution box plots of TNTXQTQL and NOQLTX metrics for reference (n = 10) and range of condition sites (n= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score.

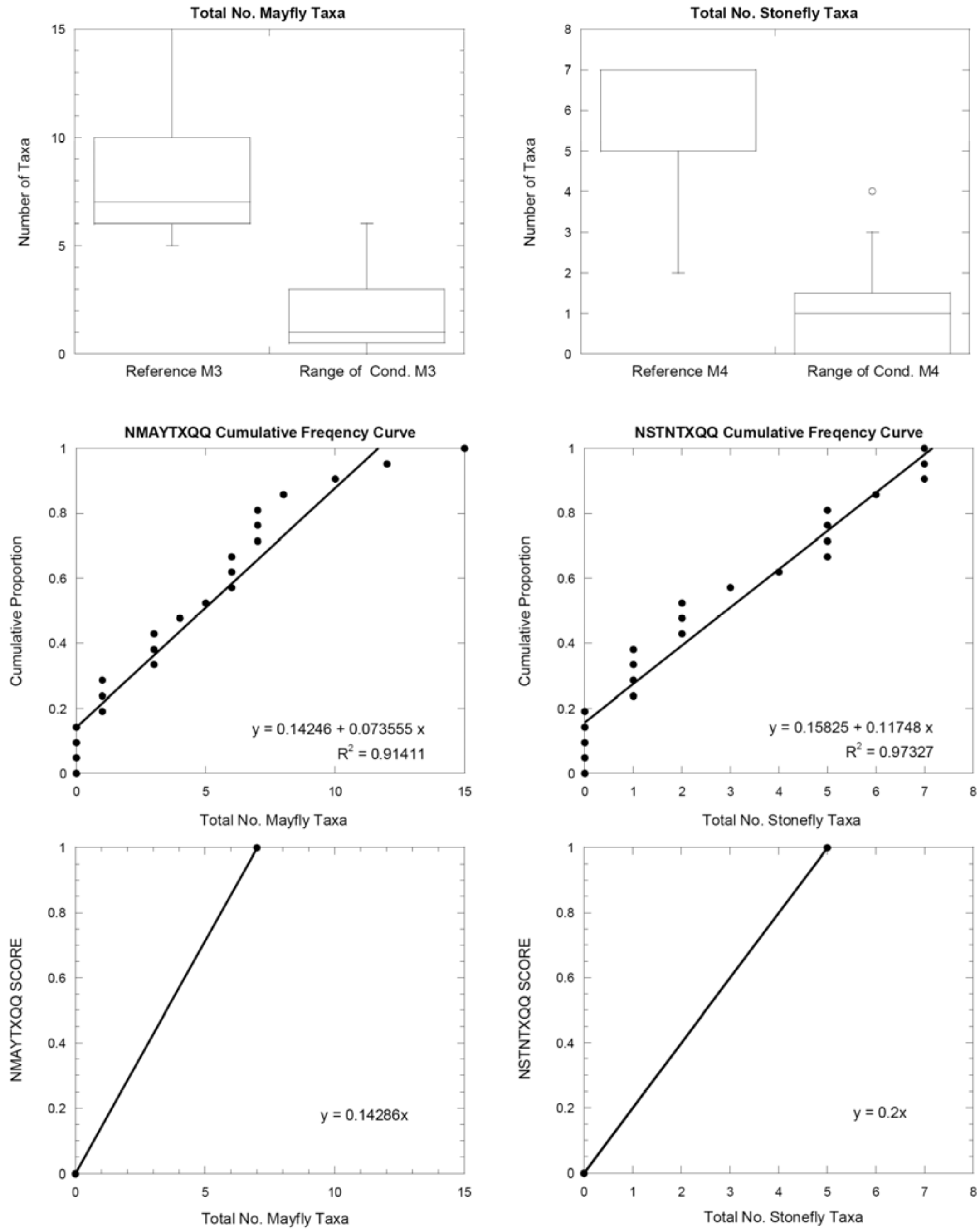

Figure 2.14. Distribution box plots of NMAYTXQQ and NSTNTXQQ metrics for reference (*n* = 10) and range of condition sites (*n*= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score.

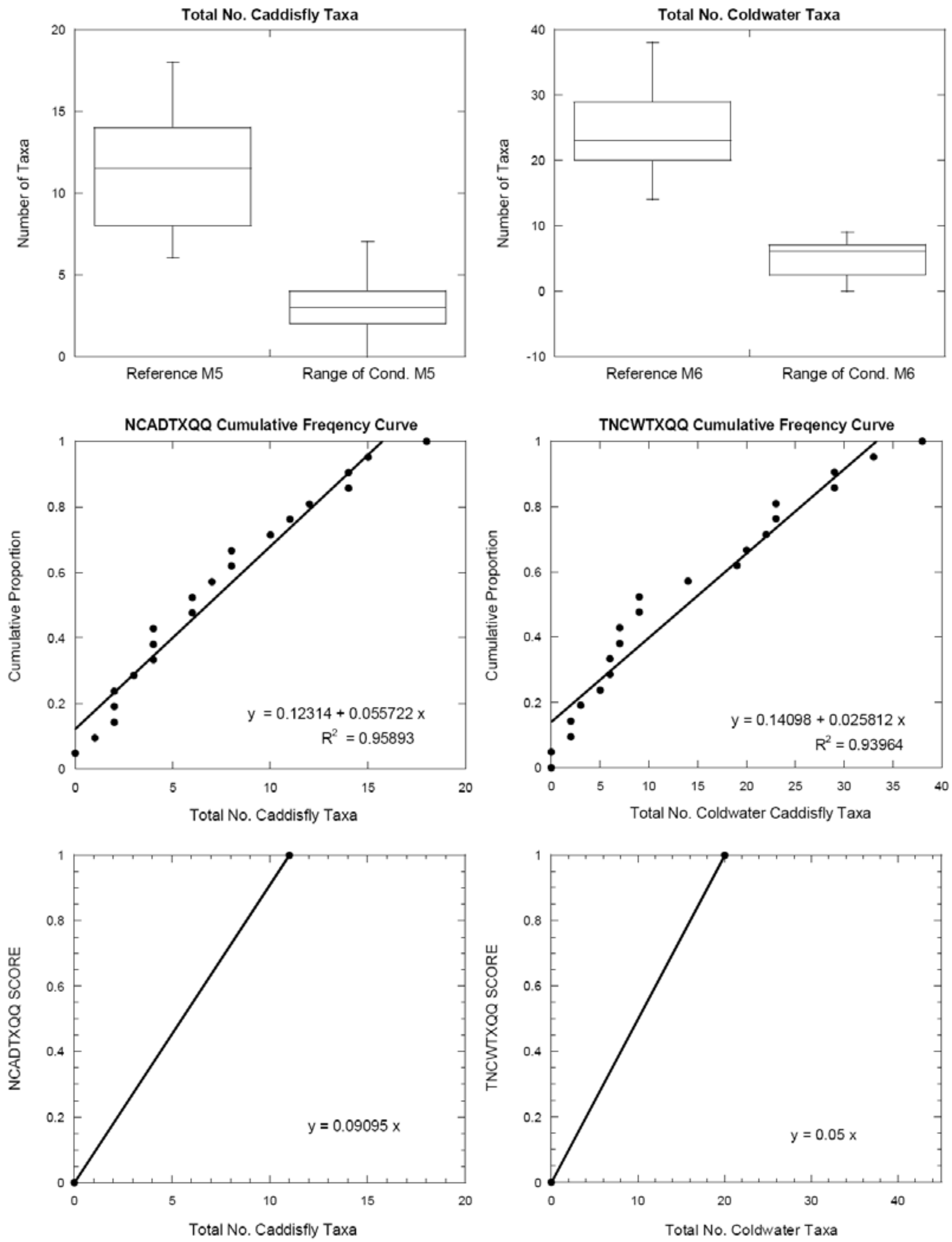

Figure 2.15. Distribution box plots of NCADTXQQ and TNCWTXQQ metrics for reference (*n* = 10) and range of condition sites (*n*= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score.

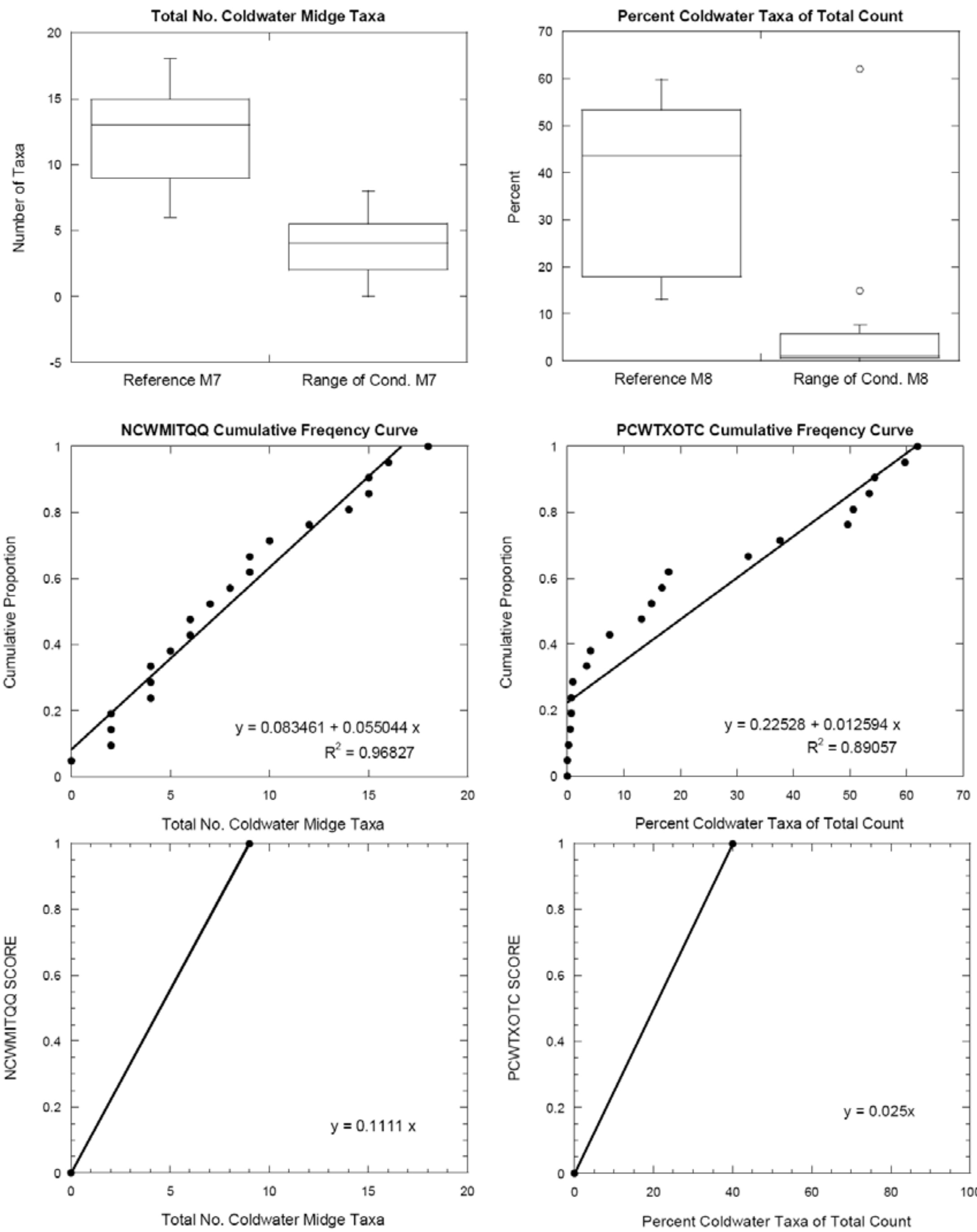

Figure 2.16. Distribution box plots of NCWMITQQ and PCWTXOTC metrics for reference (*n* = 10) and range of condition sites (*n*= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score.

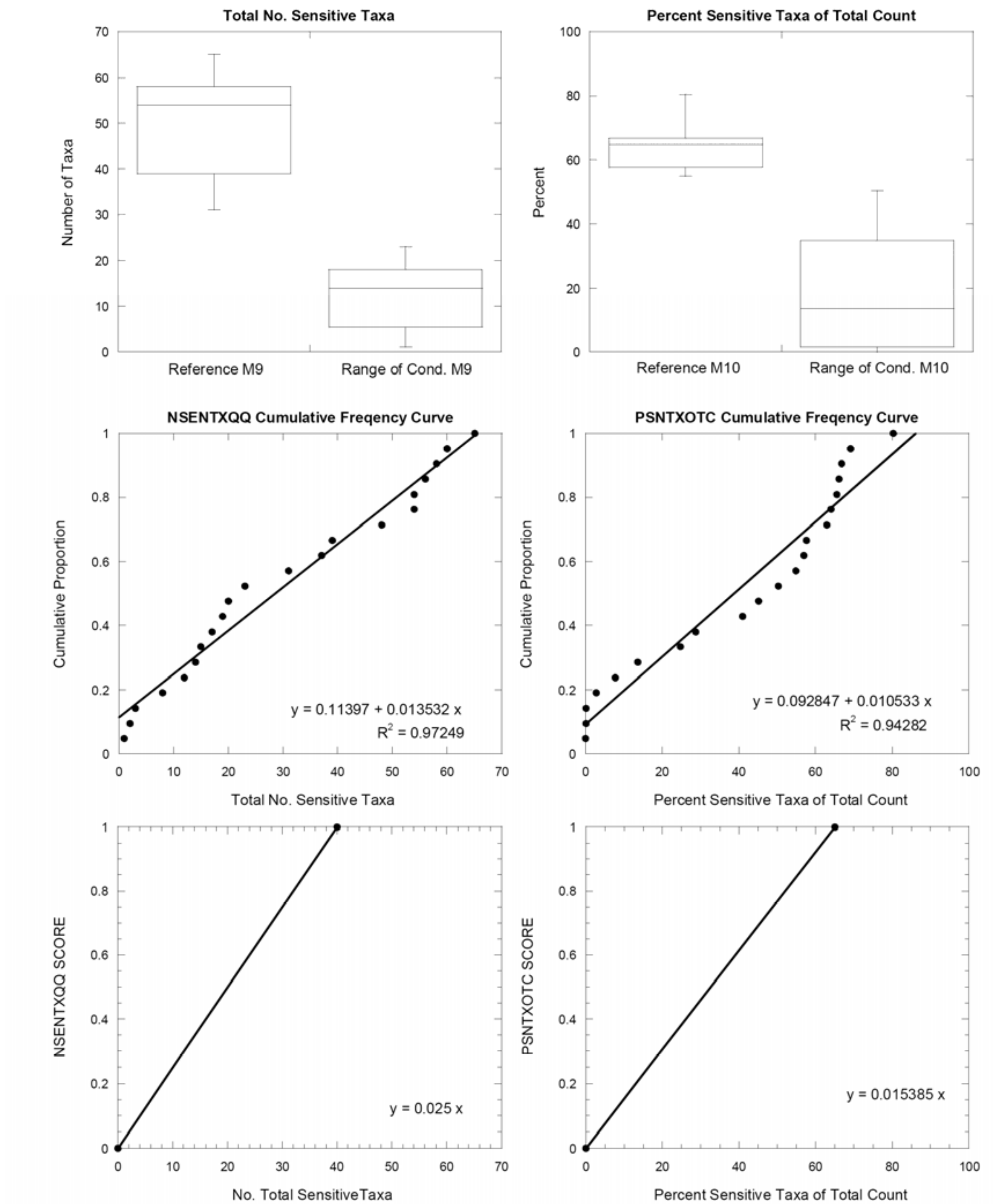

Figure 2.17. Distribution box plots of NSENTXQQ and PSNTXOTC metrics for reference (n = 10) and range of condition sites (n= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score.

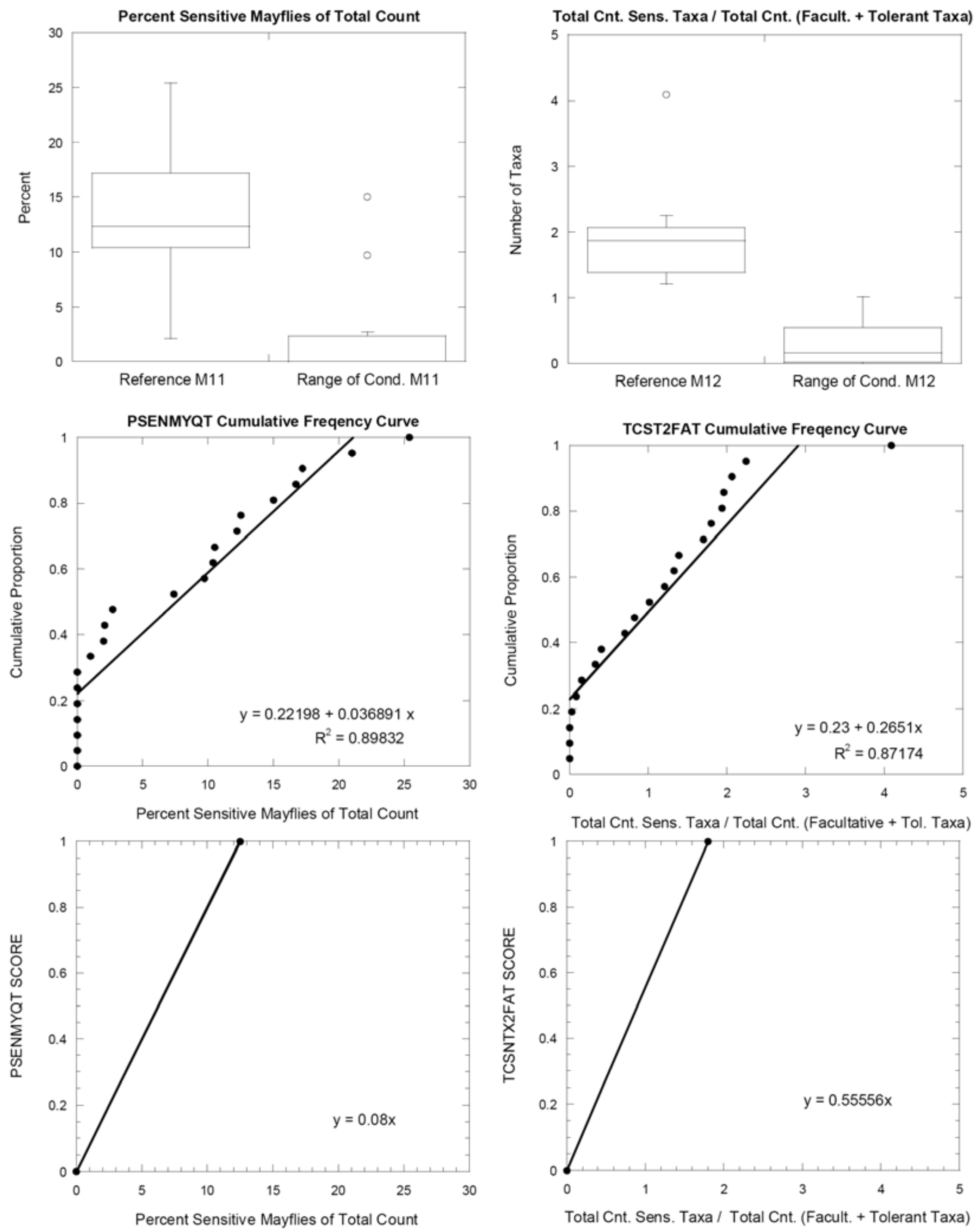

Figure 2.18. Distribution box plots of PSENMYQT and TCST2FAT metrics for reference (n = 10) and range of condition sites (n= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0 to 1 is multiplied times the value of metric to get final metric score. Abbreviation of count = cnt..

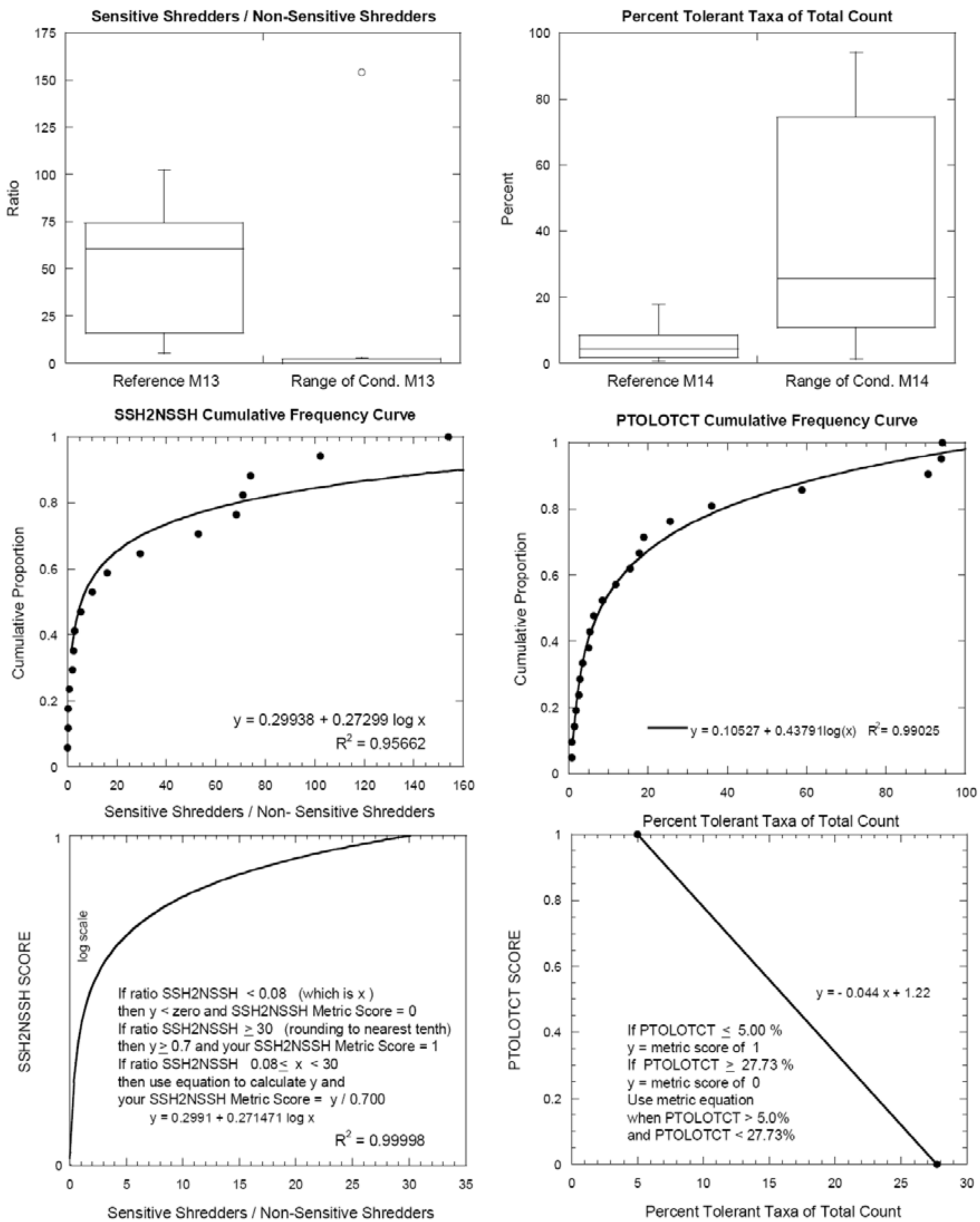

Figure 2.19. Distribution box plots of SSH2NSSH and PTOLOTCT metrics for reference (*n* = 10) and range of condition sites (*n*= 11). Cumulative frequency fitted curves of combined data from each metric shows curve shape of data relationship using curve-fitting function from graphing program (Kaleidograph, Synergy Software, 2005). Scoring equation curves (e.g., line or other) are calculated after determination is made what is the minimum value in the reference site distribution set where the highest metric score of 1 is attained. Metric score of 0-1 is multiplied times the value of metric to get final metric score.

the range of condition from reference conditions to the most impacted sites. Most were linear relationships, and the median was often the minimum full score (of 1) for many selected invertebrate metrics (Figures 2.13 - 2.19).

There were six high quality reference sites used for the quantitative comparison sampling and analysis. Each replicate from those six reference sites were analyzed separately and as a result the sample data was essentially census data. With the larger organisms, the vast majority of those EPT taxa and other larger macroinvertebrates would have been selected and identified during the prescreening sort of unique taxa. The midges identified in each replicate totaled far above the normal amount of midges sampled – usually between 100 ± 20% (OEPA 2008). There was a significant percent of less common midge taxa which likely would not have been identified in the normal sample identification process. There was approximately 45% more (or 22) midge taxa identified because of separately analyzed replicates in the quantification sample comparisons (Tables 2.14 - 2.16).

If that total of extra identified midges (22) was subtracted from these six reference sites, the two adjusted median values were 83 for the metric, total no. taxa (TNTXQTQL). Site C2, the North Branch Unnamed Tributary (UT) to UT to Big Darby Creek, adjacent to site C5 (the south branch tributary - one of the six reference site samples described above), was a high quality reference sample site with a quantitative bucket sample composited and analyzed according to normal OEPA protocols (OEPA 2008). It contained 83 total taxa identified by

Site Name	Number Midges Identified	Mean Number / Replicate	Std. Error	95% Confidence Interval		Total No. Midge Taxa	Number Likely Not Identified	Lower Midge Taxa Total
NC1	1162	145.25	25.058	86	204.5	50	25	50%
NE3	3150	393.75	85.314	192	595.5	41	17	41.5%
NE2	1540	216.17	63.169	53.8	378.6	50	22	44%
C5	1107	138.38	17.995	95.8	180.9	48	17	35.4%
C9	5061	632.62	85.542	606.7	858.5	63	32	50.8%
NE6	1562	195.25	19.697	148.7	241.8	46	21	45.7%

Table 2.14. Midge totals identified in six selected Primary Headwater Habitat reference sites collected in Ohio streams in spring to fall 2004-05 for quantitative sampling methods comparisons versus normal Ohio Environmental Protection Agency protocols.

Site Name	Number Midges Identified	Mean Number / Replicate	Std. Error	95% Confidence Interval		No. Sens. Midge Taxa	Number Likely Not Identified	Lower Sens. Midge Taxa Total
NC1	1162	145.25	25.058	86	204.5	30	12	40%
NE3	3150	393.75	85.314	192	595.5	22	9	41%
NE2	1540	216.17	63.169	53.8	378.6	30	14	46.70%
C5	1107	138.38	17.995	95.8	180.9	28	11	39.30%
C9	5061	632.62	85.542	606.7	858.5	32	17	53%
NE6	1562	195.25	19.697	148.7	241.8	26	14	53.80%

Table 2.15. Midge and sensitive (Sens.) midge totals identified in six selected Primary Headwater Habitat reference sites collected in Ohio streams in spring to fall 2004-05 for quantitative sampling methods comparisons versus normal Ohio Environmental Protection Agency protocols.

Site Name	Number Midges Identified	Mean Number / Replicate	Std. Error	95% Confidence Interval		No. CW Midge Taxa	Number Likely Not Identified	Lower CW Midge Taxa Total
NC1	1162	145.25	25.058	86	205	16	5	31%
NE3	3150	393.75	85.314	192	596	15	4	26.7%
NE2	1540	216.17	63.169	53.8	379	15	6	40%
C5	1107	138.38	17.995	95.8	181	14	3	21.4%
C9	5061	632.62	85.542	606.7	859	13	4	30.8%
NE6	1562	195.25	19.697	148.7	242	18	7	38.9%

Table 2.16. Midge and coldwater (CW) midge totals identified in six selected Primary Headwater Habitat reference sites collected in Ohio streams in spring to fall 2004-05 for quantitative sampling methods comparisons versus normal Ohio Environmental Protection Agency protocols.

normal procedures (Figure 2.13) which matched the revised totals above. Therefore, the total taxa value of 83 was chosen to be the minimum total number of taxa to receive a full metric score of 1 for the invertebrate metric TNTXQTQL.

Based on the reference site distribution the median values for the invertebrate metric total no. qualitative taxa (NOQLTX) was 31 and 33 (Figure 2.13). Therefore, the total of 32 was selected for the final invertebrate metric NOQLTX as the minimum number of taxa collected during the qualitative sample to score a maximum metric score of one.

The invertebrate metric, total number of mayfly taxa, had a strong linear relationship (r^2=0.91411) from the range of condition sites with good distribution ascending to six into the minimum totals for the reference sites (Figure 2.14). The median total number of mayflies in the reference sample sites was seven and was chosen to be the minimum invertebrate metric score to receive the maximum metric score (1).

The total number of stonefly taxa metric, NSTNTXQQ, had a very strong linear relationship based on the coefficient of variation of 0.97 (Figure 2.14). There was some overlap of tails where some non-reference sites still had very good substrates and intact riparian corridors which kept stream temperatures lower. Spring Creek (site NE4), a wooded stream in the Cuyahoga Valley Recreation Area, still had 3 stonefly taxa present despite some chemical inputs. A PHWH ravine tributary to the Olentangy River (site C6) was partially protected by its rocky bedrock structure and substrates which still allowed 4 stoneflies to be collected despite a large sediment bedload washed downstream from temporary stream manipulation and housing construction. Stable watersheds were a key for a high score with this metric. The median and 25th percentile of reference sites was a total of five stoneflies which was selected as the minimum reference total to receive a full score for the metric NSTNTXQQ.

The distribution data for the invertebrate metric, total number of caddisfly taxa (NCADTXQQ), showed an almost even distribution (Figure 2.15). The median values in the reference sites data set was 11 and 12 caddisfly taxa. The minimum full metric score was conservatively picked to be 11 for NCADTXQQ.

The distribution of sites with the invertebrate metric, total number of coldwater taxa (TNCWTXQQ), was highly related to riparian width, general isolation of basin and intact natural (wooded or springs) headwaters above the sample point, and percent forest cover (Figures 2.2, 2.6). Only one of the top eight reference site totaled less than 235 meters of riparian width – with a high of 750 meters. Only one in the top eight reference sites had less than 44% forest cover with two at 95% and 100%, respectively. All of the top eight sites had mostly intact upper watersheds. Seven of the eight were in protected areas or parks. The coldwater midges included in this metric may have increased totals slightly (Table 2.16), but the main reason for choosing the 25th percentile was that there was not any overlap between the reference sites and the range of condition sites (Figure 2.15). If the likely unidentified CW midges from Table

2.16 were reduced from the highest quality reference sites, the CW totals were still in the same range. The total of 20 CW taxa was still at the approximate 25^{th} percentile, therefore I chose 20 coldwater taxa as the minimum total which received the full metric score for TNCWTXQQ.

I chose the 25^{th} percentile of 9 coldwater midges for the metric, total number of CW midges (NCWMITQQ), as appropriate with this metric. First the invertebrate metric NCWMITQQ had a lower diversity total to begin with – 18 taxa was the maximum collected at the one of the best reference sites. Also, the median would be between 10 and 9 (presently the 25^{th} percentile) with adjusted coldwater midge totals for the top reference sites (Figure 2.16). With that information, it seemed prudent and appropriate to use the 25^{th} percentile of 9 CW midge taxa as the minimum total to receive a full metric score for NCWMITQQ.

The metric, percent coldwater taxa of total taxa (PCWTXOTC), was a metric to discern differences between the highest quality sites. The impaired sites had a very small range (Figure 2.16). With that in mind the median CW taxa percentages were 37.63% (5) and 49.55% (6), so the median concentration used to determine a full metric score was 40 percent. This allowed for differentiation and illustration of degrees of quality.

The normal median for scoring the metric, number of sensitive taxa (NSENTXQQ), seemed very high (Figure 2.17). The range of the reference site values for NSENTXQQ was 34 (high of 65 versus low of 31). The mean between the ranges was 48 total taxa. The six highest reference sites were increased from the extra midge sampling (Table 2.15). There was one normally sampled reference site that was equal to the total of 48 – site C2 (the North Branch UT to UT to Big Darby Creek). However if the first six reference site totals were reduced by the likely unidentified sensitive midge totals, then only two sites would have received a full score for the metric. The mean of 48 total sensitive taxa from the ranges should and was also be reduced by half the midge decrease (six) which gave a total of 42 sensitive taxa. The adjusted reference site sensitive taxa totals now gave the median values of 42 and 45. There was also a gap in the cumulative frequency curve between 40 and 50. Considering all these factors, I decided the reduced median of 42 total sensitive taxa (or the adjusted mean score of the range of reference sites) was selected as the minimum total sensitive taxa to attain a full metric score for NSENTXQQ - the number of total sensitive taxa.

This was another metric to separate the highest quality sites and was one of the unique groups in PHWH streams– the high percentage of sensitive taxa in the invertebrate community. The median for the invertebrate metric, percent sensitive taxa of total count (PSNTXOTC), was at 65% with the five top quality reference sites having higher percentages of sensitive taxa. This median value of 65% was mostly centered in the range for the reference sites which ranged from a high of 80.34% to a low of 54.85% (Figure 2.17). So the minimum full metric score of 1 for the invertebrate metric, PSNTXOTC, was set at 65%.

The metric, percent sensitive mayfly taxa of total count (PSENMYQT), was included to illustrate changes to this sensitive taxa group. The reference site median values were 12.5% and 13.0%, respectively (Figure 2.18). The range of reference sites extended down to 2% with vey little overlap from the range of condition sites, so I chose the lower median total value of 12.5% mayfly taxa for the minimum percentage attaining a full metric score of 1 for PSENMYQT.

The ratio, total count (sensitive taxa / facultative and tolerant taxa) (TCST2FAT), showed a continuous linear relationship notwithstanding the highest ratio of > 4 (outlier). The impaired sites ranged from 0 to a ratio of 1.01 with the lowest reference site ratio value documented at 1.21 and increased to 4 (Figure 2.18). The median TCSNT2FAT ratios were 1.80 and 1.94. I chose the lower median value, as it seemed more appropriate given the distribution. So a ratio $\geq$ 1.80 scores a full metric score of 1 for TCTST2FAT. A lot of ecological information on macroinvertebrate community quality and possible stresses will be available from TCTST2FAT.

The selected count metric, number of sensitive shredders / number of non-sensitive shredders (SSH2NSSH), will give insight into macroinvertebrate community health and any changes in subsequent monitoring activities. Those sites with only sensitive shredder taxa in their sample scored a SSH2NSSH metric score of 1. Any SSH2NSSH ratio $\geq$ 30 scored a metric score of 1. This metric had a logarithmic relationship with a very good Coefficient of Variance (R^2 = 0.95662) (Figure 2.19). The tails of the curve were asymptotic, so the

SSH2NSSH metric scoring curve only scored differently to certain values at each extreme with the scoring curve almost identical to the frequency distribution curve. There was a lower metric ratio limit different than zero that attained a metric score of 0 – where the SSH2NSSH metric ratio is < 0.08 (Figure 2.19).

The final invertebrate metric, percent tolerant taxa of total count (PTOLOTCT), was considered a negative metric (Figure 2.19). Sites with lower percent tolerant taxa usually contained higher diversity and a higher quality macroinvertebrate community. An increase in tolerant taxa usually indicated negative impact effects, as the impaired sample sites illustrated. The cumulative frequency curve was highly correlated to the PHWH site data results with a coefficient of variation (r^2) of 0.99025 (Figure 2.19). The median reference metric concentration of 5.00%, between 4.99% (5) and 5.25% (6), was chosen, as it seemed the tolerant community totals increased above this percentage with increasingly open canopy and related increased negative inputs (e.g., sediment, nutrients, increased water temperatures). The median PTOLOTCT value of 5.00%, which equaled 0.412, was chosen to be the maximum value to receive a full metric score of 1, so PTOLOTCT values $\leq$ 5.00% scored a metric score of 1. All of the reference site data at the PHWH sample sites were $\leq$ 17.8% (Figure 2.19). State wide data had scored 0 points for any percent tolerant taxa score > ~27-28% (DeShon 1995). PTOLOTCT values of 27-28% were higher than the median in the range of condition sites, and only 5 of 21 PHWH sites (range of 35-94% tolerant taxa) scored a zero with that maximum concentration cutoff. The portion of the curve between 5% and 28% was a negative linear relationship (Figure 2.19). Therefore, the scoring equation, $y = -0.044x + 1.22$, was used to calculate the metric score between 1 and 0 for a tolerant taxa concentration of > 5.00% and < 27.73% (Figure 2.19).

PHWH ICI Metric Scoring Example

The scoring of invertebrate metrics for invertebrate data from site C2 (no. 14 – north Big Darby Creek tributary) was used to demonstrate scoring procedures. The totals (x) for each metric were listed on the PHWH ICI scoring sheet and totaled (Tables A.1, A.17). The totals for metric numbers 1 (TNTXQTQL), 2 (NOQLTX), 7 (NCWMITQQ), and 9 (NSENTXQQ) were > 1 when multiplied by the respective equations. All four of those metrics scored a maximum metric score of 1 (Table A.17). Metric number 11 (PSENMYQT) equaled exactly 1.0 when scored. The other metrics among the first 12 metrics scored between 0 and 1 (Table A.17). The three percent metrics (PCWTXOTC, PSNTXOTC, and PSENMYQT) were scored with x equal to the actual percentages to get the appropriate metric scores (e.g., 16.49%, 57.0%, and 12.5%, respectively (Table A.17). The trophic metric, SSH2NSSH, scored 1 because the ratio was 71 and ≥30 (Table A.17). The percent tolerant metric, PTOLOTCT, contained 17.5% tolerant taxa. Since that total was < 27% and > 5% the equation for the line was used: $y = -0.044x + 1.22$ to get the metric score between 1 and 0. PTOLOTCT, a negative metric which had a negative sloped scoring line (Figure 2.19), scored a metric score of 0.437 (Table A.17).

The individual metric scores were added, multiplied by 7 or completed in reverse order (Table A.17). Then the subtotal of 81.096 was multiplied by the constant (1.0204) to get the final score of 82.7 (out of 100) for the PHWH ICI at site C2 (number 14) (Table A.17).

Final PHWH ICI Scores and Correlation

The PHWH ICI scores for the reference sites and range of condition sites seemed appropriate and were very plausible and explainable knowing the characteristics of particular sample sites. All ten reference sites scored higher than the range of condition sites (Table 2.17).Seven of the top eight PHWH ICI scores correlated to the highest HMFEI scores (Table 2.17). The highest scoring disturbed sample site (NE4) was located in the Cuyahoga Valley Recreation Area with a largely wooded watershed and high quality substrates (i.e., high HHEI of 79.0). The two lowest PHWH ICI scores corresponded to the lowest HMFEI scores. PHWH ICI scores in the range of 30-60 were associated with HMFEI scores from 21-30 (Table 2.17). The correlation of final PHWH ICI scores and HMFEI scores was 0.85454 (r^2) with r=0.924 which was statistically significant at $P < 0.010$ (alpha level of 0.01, critical value of 0.537, and df of n-1=20) (Sokal and Rohlf 1973) (Figure 2.20).

The low correlation of 0.0542 (r^2) for the PHWH ICI and the Headwater Habitat Evaluation Index (HHEI) was in part related to data from biologically impaired sites with good habitat (Figure 2.21). The HHEI was developed to help predict the presence of reproducing populations of Class III salamander indicator species, not to determine the biotic integrity of the stream communities (OEPA 2002a). Farver (2004) also found no significant association between the HMFEI score and HHEI scores within the category of Class III PHWH streams in Ohio.

Site Name	Site Type	PHWH ICI	HMFEI
NC1	Reference	100.0	48
NE6	Reference	98.6	49
NE2	Reference	98.4	47
C9	Reference	96.2	49.5
C5	Reference	94.9	49
NE5	Reference	91.5	42
NE3	Reference	88.3	36
C2	Reference	82.7	42
NC2	Reference	81.6	30
C7	Reference	79.7	46
NE4	Range of Condition	55.3	30
NC11	Range of Condition	53.0	28
NC10	Range of Condition	45.6	22
NC9	Range of Condition	41.4	28
C6	Range of Condition	34.6	21
C3	Range of Condition	28.2	26
NE1	Range of Condition	27.0	11
C8	Range of Condition	24.7	27
NC8	Range of Condition	11.6	21
NC3	Range of Condition	11.0	7
NC7	Range of Condition	7.8	6

Table 2.17. Final PHWH ICI scores ranked and compared to HMFEI scores from PHWH sample sites in central, north-central, and northeast Ohio in spring to fall of 2004-05.

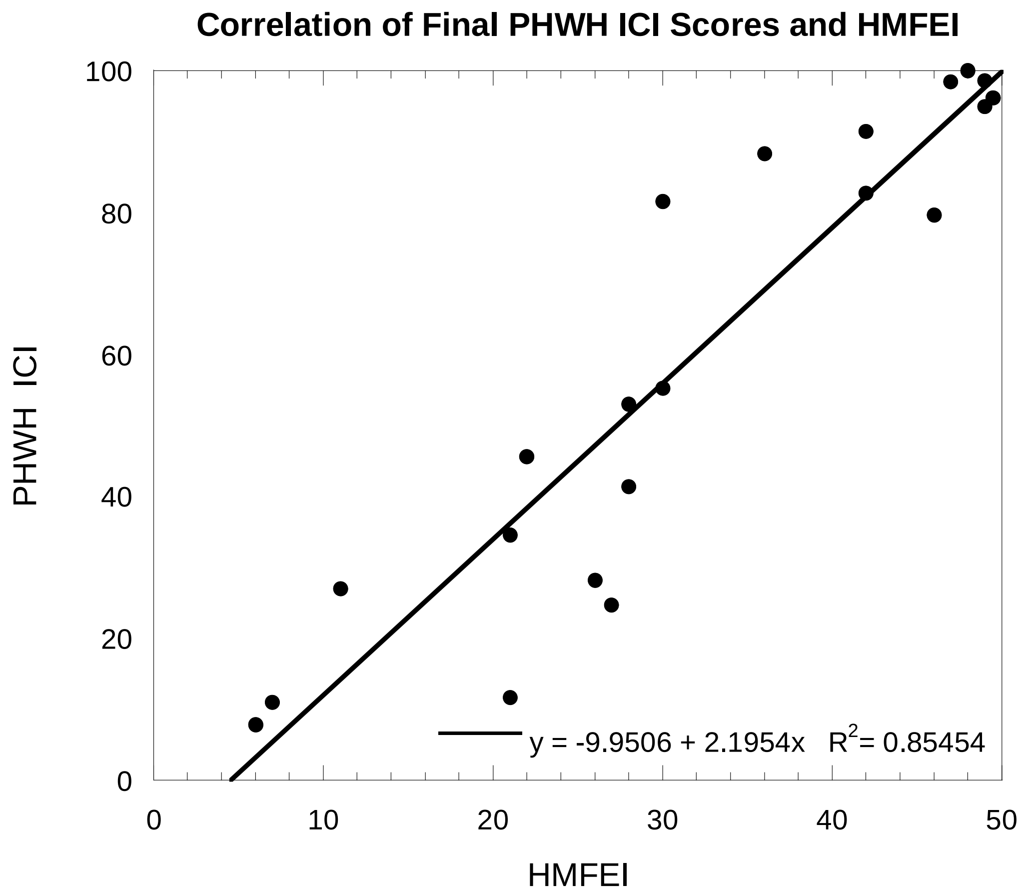

Figure 2.20. Correlation of final Primary Headwater Habitat Invertebrate Community Index (PHWH ICI) scores and Headwater Macroinvertebrate Field Evaluation Index (HMFEI) at selected PHWH sites sampled in central, north-central, and northeast Ohio, in spring to fall 2004-05.

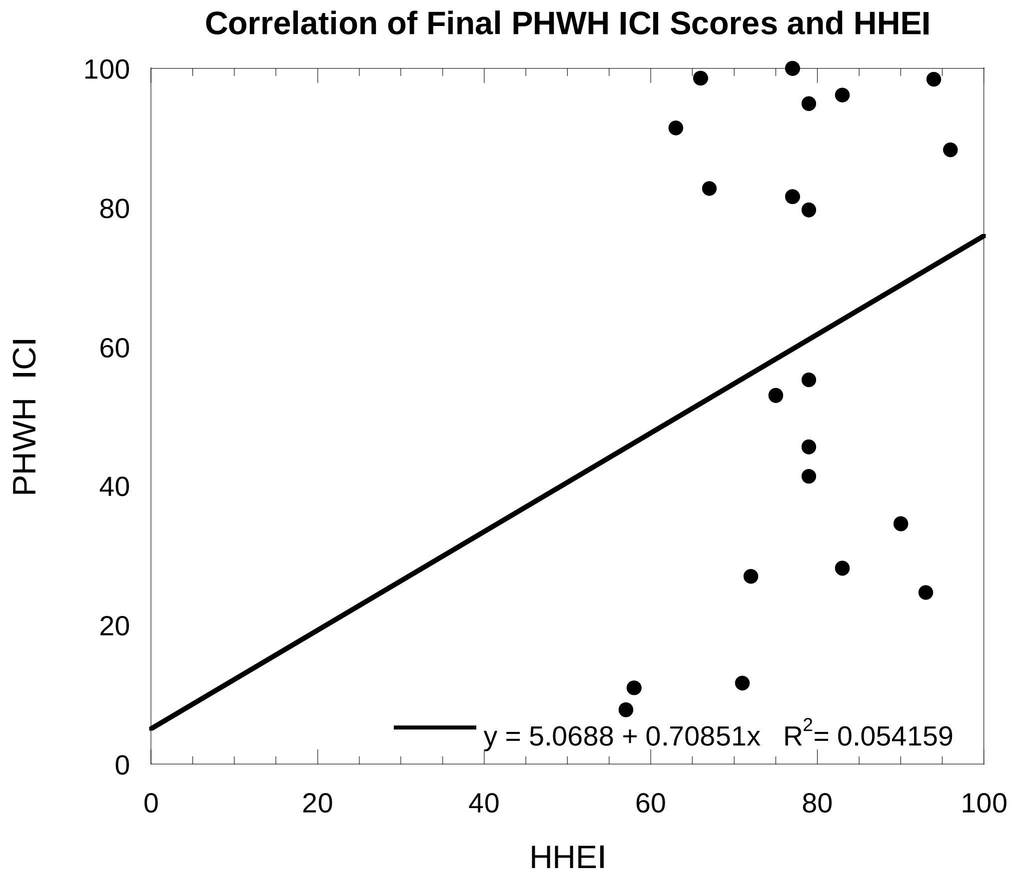

Figure 2.21. Correlation of final Primary Headwater Habitat Invertebrate Community Index (PHWH ICI) scores and Headwater Habitat Evaluation Index (HHEI) at selected PHWH sites sampled in central, north-central, and northeast Ohio, in spring and fall 2004-05.

Applicability of PHWH ICI

An example of appropriateness for scoring and illustrating differences in quality between sites was PHWH sites C5 and C2 (Table 2.17). Both sample sites were tributaries to Big Darby Creek and in adjacent subwatersheds. The north branch (site C2) contained more tilled land in its watershed boundaries and was still recovering from agricultural inputs though the farming activity had been significantly decreased for a two years (Figure 2.22). The south branch site (C5) had much less agricultural influences due to a wider riparian corridor and scored a much higher PHWH ICI– 94.9% to 82.7%, respectively (Table 2.17).

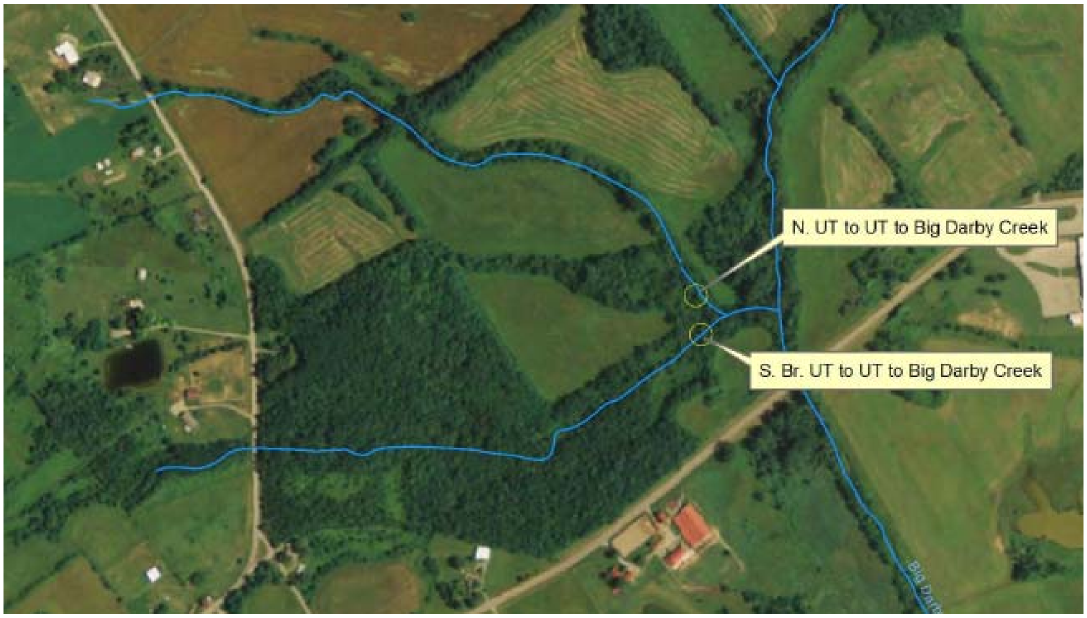

Figure 2.22. Aerial photo of subwatersheds for Primary Headwater Habitat (PHWH) sites C2 (north branch) and C5 (south branch) in the Big Darby Creek watershed, Logan County, Ohio sampled in fall 2005.

A site showing a negative impact despite decent habitat was sample site NC3 which scored a very low PHWH ICI of 11.0 (Table 2.17). This site, in Wayne County upstream from Smithville, Ohio, was a tributary to Sugar Creek, a largely agricultural area with a large amount of dairy operations (Moore 2002). Site NC3 had stream canopy adjacent to a portion of the stream, but the upper reach was not protected by a riparian corridor or the corridor was broken, narrow, and patchy. Nonpoint source inputs from agricultural runoff (including sediment), a horse corral, and some small developed areas upstream caused the fully shaded sample reach to be chemically impaired. The patchy nature of the upper watershed left this tributary vulnerable to negative inputs affecting the stream community quality. In this case, an improvement in the upstream corridor and increased canopy cover along the stream would improve quality

CONCLUSION

Quantitative Sampling Methods Comparison

Through various comparative and statistical analyses of the quantitative macroinvertebrate data from the quantitative sample methods comparison, the bucket method seemed to give the best possible opportunity for the highest diversity and most complete quantitative macroinvertebrate data collection in these Primary Headwater Habitat streams. Analysis of quantitative data from the six selected PHWH sample sites determined that the USEPA Bucket sample method data was best of those three compared methods and was used for the PHWH quantitative data analyses for PHWH index development.

Primary Headwater Habitat Invertebrate Community Index Development

The Primary Headwater Habitat Invertebrate Community Index (PHWH ICI) yielded appropriate scores for the quality of sites, whether reference sites or disturbed sites and had good correlation with HMFEI scores (Table 2.17, Figure 2.20). The developed PHWH ICI seemed to be an acceptable biomonitoring tool to use in PHWH streams throughout the sampling area in the Eastern Corn Belt Plain and Erie-Ontario Lake Plain ecoregions that were sampled in Ohio and possibly other areas with similar hydro-geological characteristics (Omernik and Gallant 1988). The range of PHWH ICI scores found at reference sites was 79.7 to 100 (Table 2.17). The range of PHWH ICI scores at impacted range of condition sites was 7.8 - 55.3 with no overlap with reference sites.

Based on scoring ranges and the lowest reference site which scored a PHWH ICI of 79.7, a PHWH ICI score that met an acceptable biological performance was determined to be ≥ 70% (equal to a narrative quality assessment of good) (Table 2.17). A narrative assessment score of very good was ≥ 80%. An exceptional PHWH ICI score was greater than or equal to 90%. From ≥ 40% to < 70% the narrative evaluation would be a fair quality performance which did not meet the selected PHWH ICI criteria standards. Poor quality conditions correlated to a PHWH ICI score from 30% to < 40%, and very poor quality conditions was assessed as a score of < 30%. These accompanying narrative assessments were the same narrative quality assessments used in qualitative sampling using OEPA protocols with a range from very poor to exceptional (OEPA 2008).

From data presented in Table 2.17 a lower bound PHWH ICI score of 70.0 (70% of the maximum score of 100) is expected at a non-impacted primary headwater stream reference site in Ohio. Primary headwater streams with PHWH ICI scores less than 70.0 have a high probability that the benthic macroinvertebrate community is impaired from human disturbance, and thus not fully meeting the goals of the Clean Water Act. Where identified, these headwater streams should be high priority for development of total maximum daily load (TMDL) surveys to identify measures that need to be taken to help bring the stream into attainment of its aquatic life use potential.

CHAPTER 3

DEVELOPMENT OF A SALAMANDER COMMUNITY QUALITY INDEX FOR PRIMARY HEADWATER HABITAT STREAMS IN OHIO

INTRODUCTION

Amphibians replace fish as the primary vertebrate predator in small streams of upper watersheds (Davic and Welsh 2004). Primary Headwater Habitat (PHWH) Class III streams have perennial, cool-cold, groundwater flow and stable habitats with generally a component of rocky substrates (OEPA, 2003c). These are the habitat requirements of eight Plethodontid (lungless) salamander species or subspecies in Ohio that are primarily obligate perennial stream species where the larval rearing that normally two to five years (Petranka 1998, Pfingsten and Downs 1989). Salamander populations in Ohio with larvae >12 months and < 24 months are rare, thus nearly all Class III indicator species have larval periods two years or greater.

The obligate stream salamanders requiring Class III PHWH streams are the main focus of monitoring and protection efforts and the development of a PHWH Salamander Quality Index (SQI), because salamanders with long-lived larval periods, as biological indicators, integrate long-term ecological information for the protection of small, headwater streams (Southerland et al. 2004). The eight obligate stream salamander species from Ohio that are Class III PHWH bioindicators include (OEPA 2002a): *Eurycea bislineata* (northern two-lined Salamander), *E. cirrigea* (southern two-lined Salamander), *E. longicaudata* (long-tailed Salamander of which some populations have < 12 month larval periods and are not Class III indicators), *E. lucifiga* (cave Salamander), *Gyrinophilos porphyriticus porphyriticus* (northern spring Salamander), *G. porphyriticus duryi* (Kentucky spring Salamander), *Pseudotriton montanus diastictus* (midland mud Salamander), and *P. ruber ruber* (northern red Salamander). Monitoring and salamander sample data should include and tabulate all salamander species collected, and where possible age classes present.

Anthropogenic or human disturbance activities continue to play an important role in impacting stream ecosystems in Ohio and elsewhere (Resh et. al. 1988, Yoder and Rankin 1998). Habitat destruction or alteration (e.g. timber harvesting), chemical applications and input of runoff chemicals are generally known causes of amphibian population declines thus affecting biotic integrity (Karr et al. 1986, Semlitsch 2003). Fragmented habitats (e.g., caused by decreasing percent forest cover) can imperil stable amphibian populations by allowing upstream or adjacent changes (land use or physicochemical changes or inputs) to affect the watershed downstream from where the action occurred and could otherwise appear to be very stable habitat (Semlitsch 2003, Southerland et al. 2004,).

An important reason for developing a salamander quality index biomonitoring tool is to identify subwatersheds with increased salamander species diversity and use the data to facilitate the setting of priorities for conservation and management of priority habitat and to help develop policy protecting these sensitive areas (Myers et al. 2000). A salamander based community quality index also can be used to monitor areas of concern or to set standards for protection, remediation, or mitigation.

STUDY AREAS AND METHODS

Site Selection

Sample sites were selected from various locations in central Ohio (*n*=7), north-central Ohio (*n*=8), and northeast Ohio (*n*=6) (Table 2.1) (Figure 2.1). Central Ohio sites were located in Delaware, Logan, and Pickaway Counties. Sample sites in north-central Ohio were located in Wayne County, and northeast

Ohio sampling locations were located in Geauga, Lake, and Summit Counties (Figure 2.1). These sites were selected to capture varying site water and community quality from reference or least disturbed sites impacted from various chemical or physical inputs. Sites were geo-referenced with geographical positioning system (GPS) to include in geographic information system (GIS) landscape analysis. Quality ranged from reference condition PHWH Class III (high quality exceptional sites – based on narrative quality assessments) to good to poor quality condition (range of condition sites) along the human disturbance gradient affected by differing negative anthropogenic impacts (OEPA 2008, Yoder and Rankin 1998) (Table 2.1). Reference condition sites had consistent perennial, groundwater-fed coldwater with a high percentage of woody riparian vegetation in the stream corridor insulating the stream minimizing nonpoint source inputs and negative physicochemical inputs (OEPA, 2003c).

Sample sites consisted of 100-m reaches. From the lowest downstream position, the sampling reach was divided into three sampling zones upstream at 0-m, 33-m, and 66-m (furthest sampling point) for consistent chemical sampling.

Physicochemical and Land Use Analysis Data Collection

Physicochemical and landscape analysis data were collected at all PHWH sample sites to document the influence of adjacent and watershed-wide land use inputs related to the salamander community quality. Habitat parameters consisted of chemical, physical stream structure, and land use measurements (i.e., portions of the Headwater Habitat Evaluation Index (HHEI) like pool depth and substrate scores (OEPA 2002a) or percent forest cover and gradient as determined by USGS Streamstats) (Koltun 2002, 2006). Sample sites consisted of 100 meter reaches. Measurements were collected at the downstream sample point (0-m) and at 33- and 66-m mark. Temperature (°C), dissolved oxygen (mg/L), pH, turbidity, and conductivity (µmhos/cm^3) and were measured using an YSI 6000 multi-probe data sonde probe (Yellow Springs Instruments, Yellow Springs, Ohio). Parameters with multiple measurements (e.g., % open canopy cover or dissolved oxygen) were each consolidated to an averaged reach value. A densiometer was used to measure canopy closure in four directions at each reach mark and the three means averaged to calculate mean canopy closure (USEPA 2006). Qualitative habitat evaluations were conducted using the HHEI (OEPA 2002a) according to OEPA protocols. Environmental metrics from HHEI scored separately included substrate score, % total (slabs/boulder/bedrock/cobble), % silt and muck, riparian width (visual measure), and floodplain quality (OEPA 2002a). Floodplain quality scored 0-20 with 10 points per bank based on quality listed. Adjacent land use and perpendicular to stream channel were visually assessed according to the presence or absence of woodlots, feedlots, row crop, and residential areas. Embeddedness scores were visual assessments with the 1 to 5 score range. Embeddedness 1-5 scored a 5 if silt covered < 5% of stream substrates with a 1 for > 75% silt covered conditions (Platts et al. 1983). Land use analysis was a spatial analysis that used ArcGIS 9.2 with fifteen land cover data layers from the 2001 National Land Cover Data (NLCD) web site (USEPA 2001). A few of the measured land use variables were different levels of residential housing intensity (low, moderate, and high), impervious surface, different forest types, open water, pasture hay, and cropland among others (Appendix Tables A.7-A.9).

Salamander Sampling Data Collection

During qualitative macroinvertebrate sampling which entailed a physical search of all habitats and the use of a dip net or hand picking of substrates to collect organisms, incidental taking of salamanders occurred (OEPA 2008). The salamanders were identified and tabulated into the total site data.

Three macroinvertebrate quantitative sampling methods were collected for comparison at each sample site in the companion study. Artificial leaf packs (Davic and Skalski 2009), Surber samples, and bucket samples (USEPA 2006) were collected. A summary of incidental salamander collection results for the six reference sites compared will be tabulated and discussed as a function of, at present, the most uniform and consistent salamander collection technique. Salamander data collections from all sites were tabulated into a summary data table.

Samples were collected starting in fall 2004 and the majority of sampling occurred in to spring (May) 2005 to fall (November) 2005 after ice-out to end of the fall (freezing conditions) as recommended by Ohio EPA (OEPA 2002b).

The main quantitative salamander method used to document the presence of a reproducing salamander population was the visual encounter survey - (VES) (OEPA 2002a). A VES was conducted at all sites, usually first before water was stirred up or stream was disturbed. A ten-meter search for salamanders was conducted (OEPA 2002a). The width of the survey was the flowing area and one meter on each side. Small strainers or nets are used to capture salamanders, as rocks and other debris were moved manually to observed salamanders present underneath the structures. Identification and totals of each taxa collected were recorded. Salamanders collected in the process of qualitative and quantitative macroinvertebrate sampling were also tabulated to get a final total of types and age classes of salamanders collected at each sample site.

The salamander genus/species, totals, and any year classes observed were put in summary tables and different indices were scored and compared to determine which version of a salamander diversity index to include. The five different salamander diversity indices were created by me after comparing the metric selection approach by Southerland et al. (2004) and with input from Dr. Robert Davic. The goal was to compare a number of options with salamander metrics that could be quantified in the field yet allow for impacted sites to be statistically distinguished from reference sites. The five different possible salamander indices compared were: 1) salamander index 1 (VES only - complex); 2) salamander index 2 (simplified community level); 3) salamander index 3 (a modified community index with extra categories); 4) salamander index 4 (a modified cumulative version of community index); and 5) salamander index 5 (more complex version of the modified cumulative version of community index) (Tables 3.1-3.5).

Salamander Index 1	Points
VES only	
Presence of Class III Salamanders	
CW Species (Spring, Red, Mud, Cave, & 2-line Salamanders)	
Score for each type present	1 pt. / Each
No. of Class III Larval Year Classes	
Score for each year class present for all Class III Larvae	2 pts. / Each
NOTE- *Longtail qualifies if two larval yr. classes present (4)	
(Observed size differences / appearance)	
No. of Class III Juvenile / Adult Year classes	
Score for each year class present for all Class III Larvae	1 pt. / Each
(Observed size differences / appearance)	
Presence of Class II Salamanders	
(Dusky, Four-Toed, Streamside, or Longtail* Salamanders)	
Score for each type present	1/2 pt. / Each
No. of Class II Larval and Juvenile / Adult Year Classes	1/2 pt. / Each
Score for each year class present for all Class III	
larvae present (Observed size difference/appearance)	

Table 3.1. Salamander Index 1 for salamander index development comparison for use in Primary Headwater Habitat stream surveys.

Salamander Index 2	Points
(Combination of all Sampling Efforts)	
Verified Reproduction of Highly Sensitive Class III	10 pts.
CW Species (Spring, Red, Mud, & Cave Salamanders)	
Verified Reproduction of Moderately Sensitive CW Species	7 pts.
(Two-lined & Longtail Salamanders - 2 yrs)	
Verified Reproduction of Class II Species	3 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
No Verified Reproduction of Salamanders	0 pts.

Table 3.2. Salamander Index 2 for salamander index development comparison for use in Primary Headwater Habitat stream surveys.

Salamander Index 3	Points
(Combination of all Sampling Efforts)	
Verified Reproduction of Highly Sensitive Class III CW Species	10 pts.
(Spring, Red, Mud, & Cave Salamanders)	
Presence of Highly Sensitive CW Salamanders	8 pts.
(Spring, Red, Mud, & Cave Salamanders)	
Verified Reproduction of Moderately Sensitive CW Species	7 pts.
(Two-lined & Longtail Salamanders)	
NOTE- Longtail requires two larval yr. classes present	
Presence of Moderately Sensitive CW Species	
Two-lined Salamanders	5 pts.
Longtail Salamanders	4 pts.
Verified Reproduction of non-CW Species	3 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
Presence of non CW Salamander Species	2 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
No Verified Presence of Salamanders	0 pts.

Table 3.3. Salamander Index 3 for salamander index development comparison for use in Primary Headwater Habitat stream surveys.

Salamander Index 4	Points
(Combination of all Sampling Efforts)	
Highest TALLY SCORE FOR EACH SPECIES PRESENT	
Verified Reproduction of Highly Sensitive Class III CW Species	10 pts.
(Spring, Red, Mud, & Cave Salamanders)	
+ 2 pts. for each species with at least 2 yr. larval classes	≤ 8 pts.
Presence of Highly Sensitive CW Salamanders	8 pts.
(Spring, Red, Mud, & Cave Salamanders)	
Verified Reproduction of Moderately Sensitive CW Species	7 pts.
(Two-lined & Longtail Salamanders)	
NOTE- Longtail requires two larval yr. classes present	
+ 2 pts. for 2-Line and Longtail Salamanders with 2 yr. larval classes	2 pts.
Presence of Moderately Sensitive CW Species	
Two-lined Salamanders	5 pts.
Longtail Salamanders	4 pts.
Verified Reproduction of non CW Species	3 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
Presence of non CW Salamander Species	2 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
No Verified Presence of Salamanders	0 pts.

Table 3.4. Salamander Index 4 for salamander index development comparison for use in Primary Headwater Habitat stream surveys.

Salamander Index 5	Points
(Combination of all Sampling Efforts)	
TALLY FOR EACH SPECIES PRESENT	
For Presence of Sensitive Class III CW Species	
(Spring, Red, Mud, Cave, & Two-lined Salamanders)	
3rd-yr. Larvae (all listed except Cave)	6 pts.
2nd-yr. Larvae (all listed)	5 pts.
1st-yr. Larvae (all listed)	4 pts.
Juveniles	3 pts.
Adults	2 pts.
Presence of Moderately Sensitive Class III CW Species	
(Longtail Salamanders)	
1st-yr. and 2nd-yr. Larvae present together at site*	4 pts.
Juveniles	3 pts.
Adults	2 pts.
Presence of non CW Species	
(Dusky, Four-Toed, or Streamside Salamanders)	
Juveniles	3 pts.
Adults	1 pt.
No Verified Presence of Salamanders	0 pts.

Table 3.5. Salamander Index 5 for salamander index development comparison for use in Primary Headwater Habitat stream surveys.

RESULTS

Salamander Sample Collections

There were 32 of 96 replicate samples (33%) that collected salamanders while sampling the different qualitative and quantitative sampling methods (Table 3.6). The methods with the highest percent sampling success were the qualitative samples and the VES procedure.

Sample Type	Area Sampled (m^2) per site	No. Samples with Salamanders	Total No. Replicate Samples Collected	Percent with Salamanders	Comments
Surber Samples	0.28 m^2.	7	18	38.80%	2 with 2 different taxa
Bucket Samples	0.42 m^2.	9	48	18.80%	
Leaf Pack Samples	0.56 m^2.	5	18	27.80%	7- 10 days colonization
Qualitative (DN/HP)	Larger than above	5	6	83.30%	More area and habitat
PHWH Salamander survey VES	~20 m^2. (10 m zone) length- includes edges & wetted width)	6	6	100%	Other samples add info. to this data

Table 3.6. Cumulative salamander collection summary results of selected Primary Headwater Habitat sample sites during fall to spring of 2004 and 2005.

Salamander Species - Environment Interactions

Salamanders were collected at 19 of 21 sites (90.5%) (Table A.11). Sites without salamanders (NC7, NC8) were upstream and downstream from each other. Site NC7, the upstream site, contained 93% cropland with 0% forest cover (Table A.8). Site NC8 contained 69% cropland, 8% impervious surface, 17% low intensity residential development, and 12% developed open space (grass) with 0% forest cover. Open canopy measures for sites NC7 and NC8 were 98.3% (91-100%) and 95.5% (84-100%), respectively (Table 2.8). Percent silt and muck measures of the substrates were the highest records of all sites: 66.5% and 45.5% for sites NC7 and NC8, respectively. Riparian widths measured 2.25 meters and 0 meters, respectively, for NC7 and NC8 (Table 2.8).

The five salamander species collected during sampling were: *Eurycea bislineata* (northern two-lined Salamander), *E. longicaudata* (long-tailed Salamander), *P. ruber ruber* (northern red Salamander), *Desmognathus fuscus* (northern dusky Salamander), and *D. ochrophaeus* (Allegheny mountain dusky Salamander) (Tables A.11-A.12). All five salamander species were collected at only one site: the reference site NE2. All PHWH reference sites contained 3-5 salamander species except three: sites C2, C5 and NC2. Only *E. bislineata* was collected at PHWH sites C2, C5, and NC2 (Table A.11). Sites C2 and C5 contained the highest % cropland at 44.1% and 12.4%, respectively - except for site NE5 (55% - an arboretum). Reference sites C2 and C5 also had the highest log conductivity measures at 2.862 and 2.946, respectively (Table 2.5). Site NC2 had high % forest cover at 95% but had the highest ammonia concentration among reference sites – 0.216 mg/l (Table 2.6).

All of the other PHWH reference sites with 3-5 resident salamander species shared common positive habitat features. Riparian widths ranged from 235-750 m with a mean of 421 m (Tables 2.5-2.6). Percent forest cover averaged 56.4% with a range of 24-100%. Percent cropland ranged from 0-12.4% for 5 of the reference sites. One reference site watershed (NC1) contained 56.9% cropland. Silt and muck totals ranged from 0-5.0% (Table 2.5-2.6). Low embeddedness scores of 5 were recorded at 5 of these 6 reference sites (< 5% silt covered surface of substrates) (USEPA 2006). High quality habitat and water quality conditions prevailed where the highest diversity of salamanders occurred.

Salamander Index Development Selection Comparisons

The salamander metric scores had various ranges. Salamander Index 2 and 3 contained the lowest score range of 0-10 (Table 3.7). The Salamander Index 5 range was the largest with a range of 0-26. Index 1 and 4 had intermediate ranges (Table 3.7).

Site Name	Salamander Index 1	Salamander Index 2	Salamander Index 3	Salamander Index 4	Salamander Index 5
NC1	10	7	7	16	19
NE3	13	10	10	23	26
NE2	12	10	10	27	25
C5	6	7	7	9	7
C9	9.5	7	7	16	19
NE6	8	7	8	20	15
NC11	4	7	7	7	7
NC7	0	0	0	0	0
NC3	2	0	5	5	3
NC8	0	0	0	0	0
NC10	5	7	7	7	9
NC9	4	7	7	7	7
NE5	11	10	10	21	22
C2	4	7	7	7	7
NC2	6	7	7	9	12
C6	10	10	10	21	18
C8	3	0	5	5	5
C7	7	7	7	9	14
C3	6	7	7	9	12
NE1	3	7	7	7	7
NE4	4	7	7	7	7

Table 3.7. Comparative salamander index scores for salamander indices 1-5 for selected Primary Headwater Habitat sample sites for comparison to select Salamander Community Quality Index.

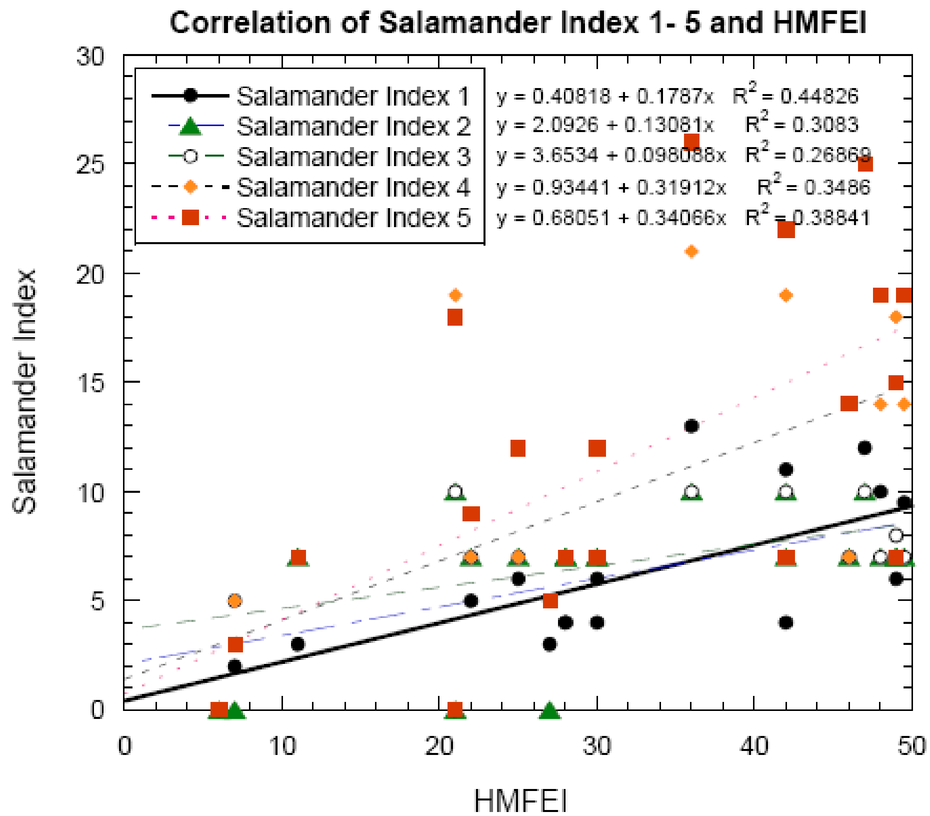

Figure 3.1. Correlation of Salamander Indices 1-5 with Headwater Macroinvertebrate Field Evaluation Index (HMFEI) in salamander index comparison scored from selected sample sites in central, north, and north-central Ohio in spring to fall 2004-05.

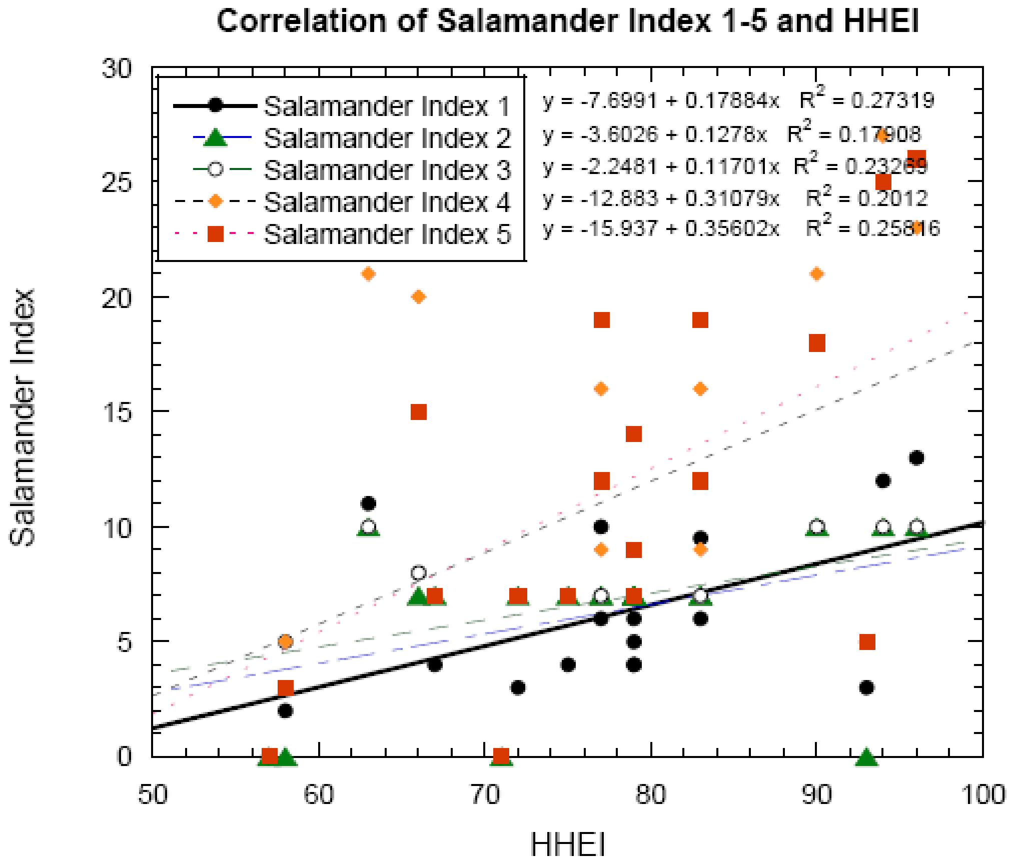

Figure 3.2. Correlation of Salamander Indices 1-5 with Headwater Habitat Evaluation Index (HHEI) in salamander index comparison scored from selected sample sites in central, north, and north-central Ohio in spring to fall 2004-05.

Salamander Community Quality Index Correlation Comparisons

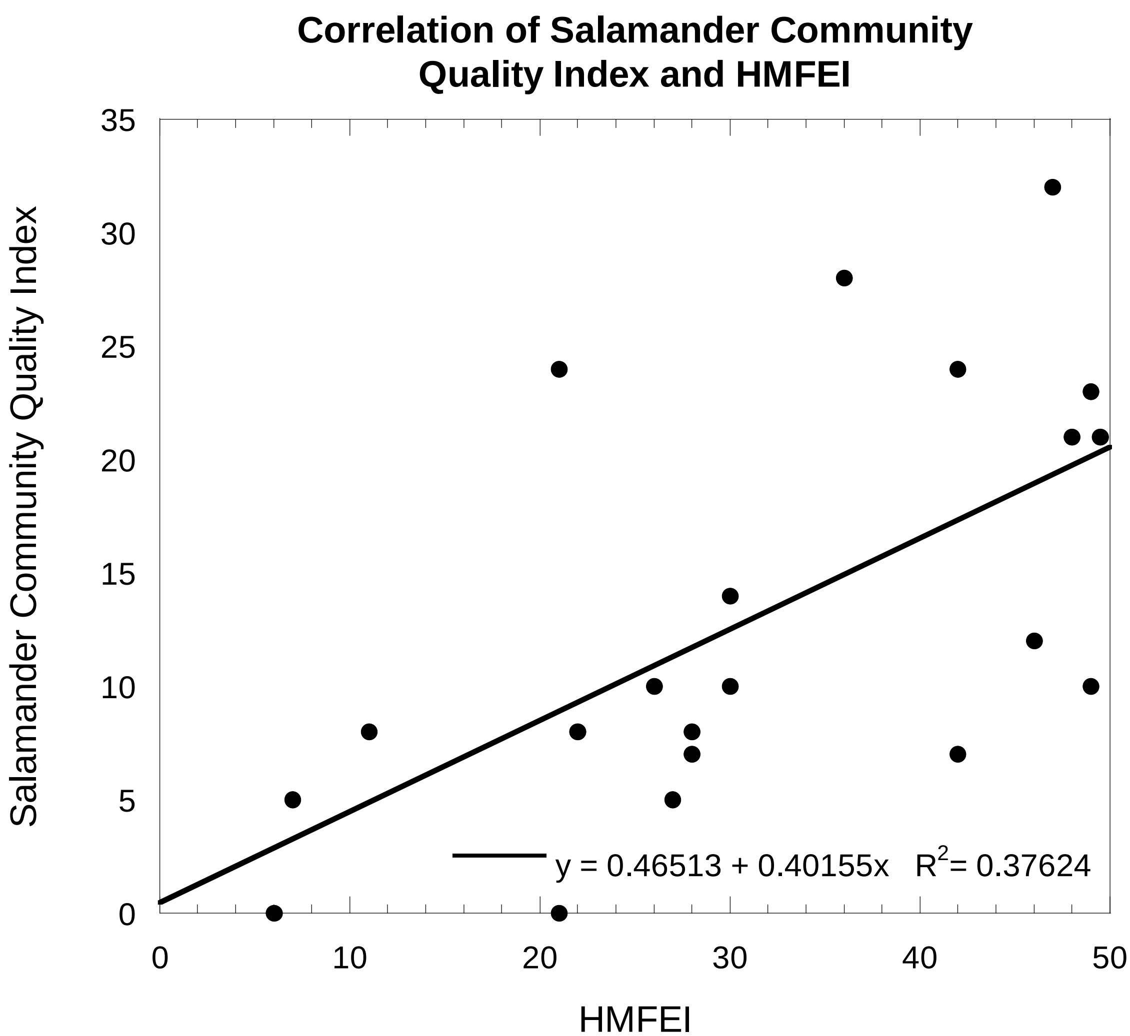

Figure 3.3. Correlation of the Salamander Community Quality Index and Headwater Macroinvertebrate Field Evaluation Index (HMFEI) for PHWH sites sampled in central, north-central, and northeast Ohio during spring to fall 2004-05.

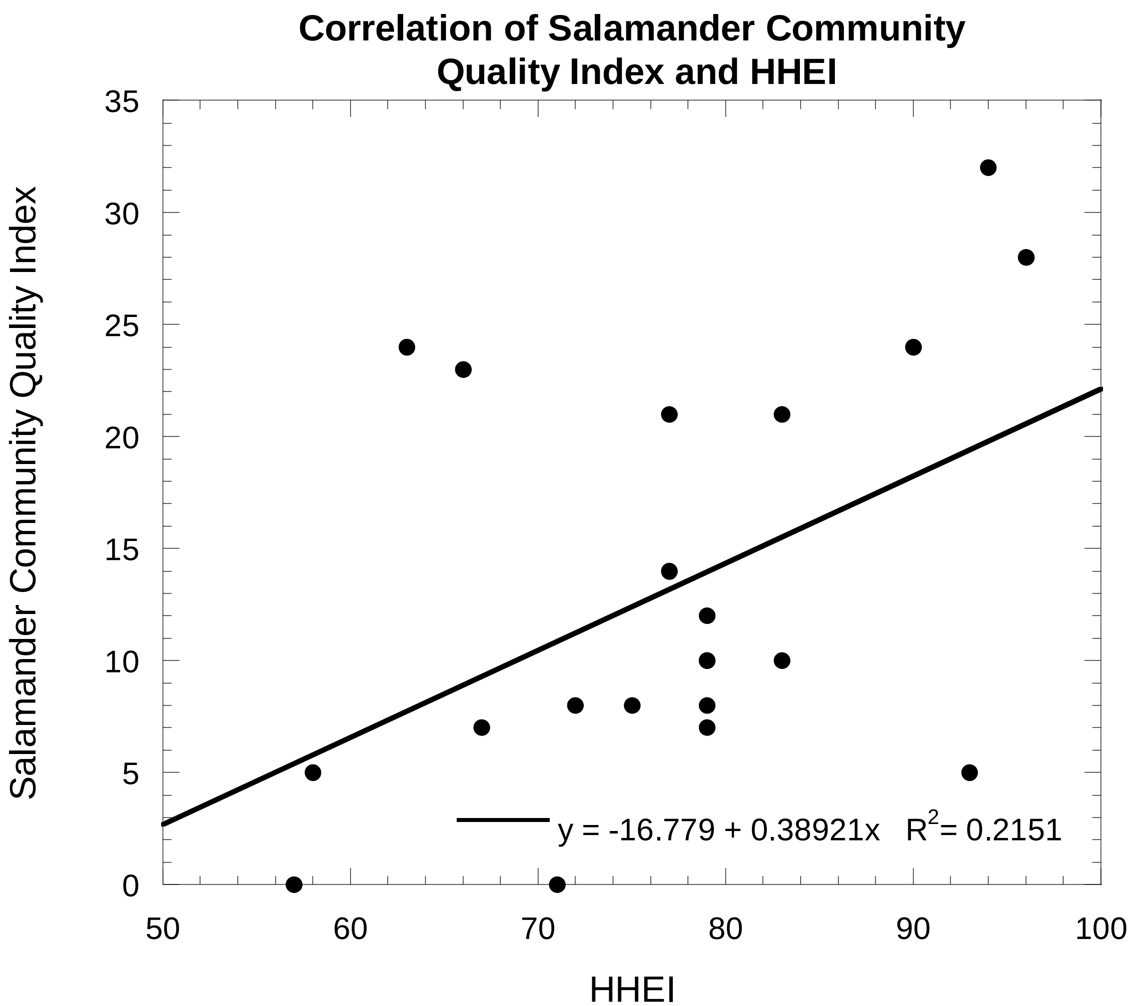

Figure 3.4. Correlation of the Salamander Community Quality Index and Headwater Habitat Evaluation Index (HHEI) for PHWH sites sampled in central, north-central, and northeast Ohio during spring to fall 2004-05.

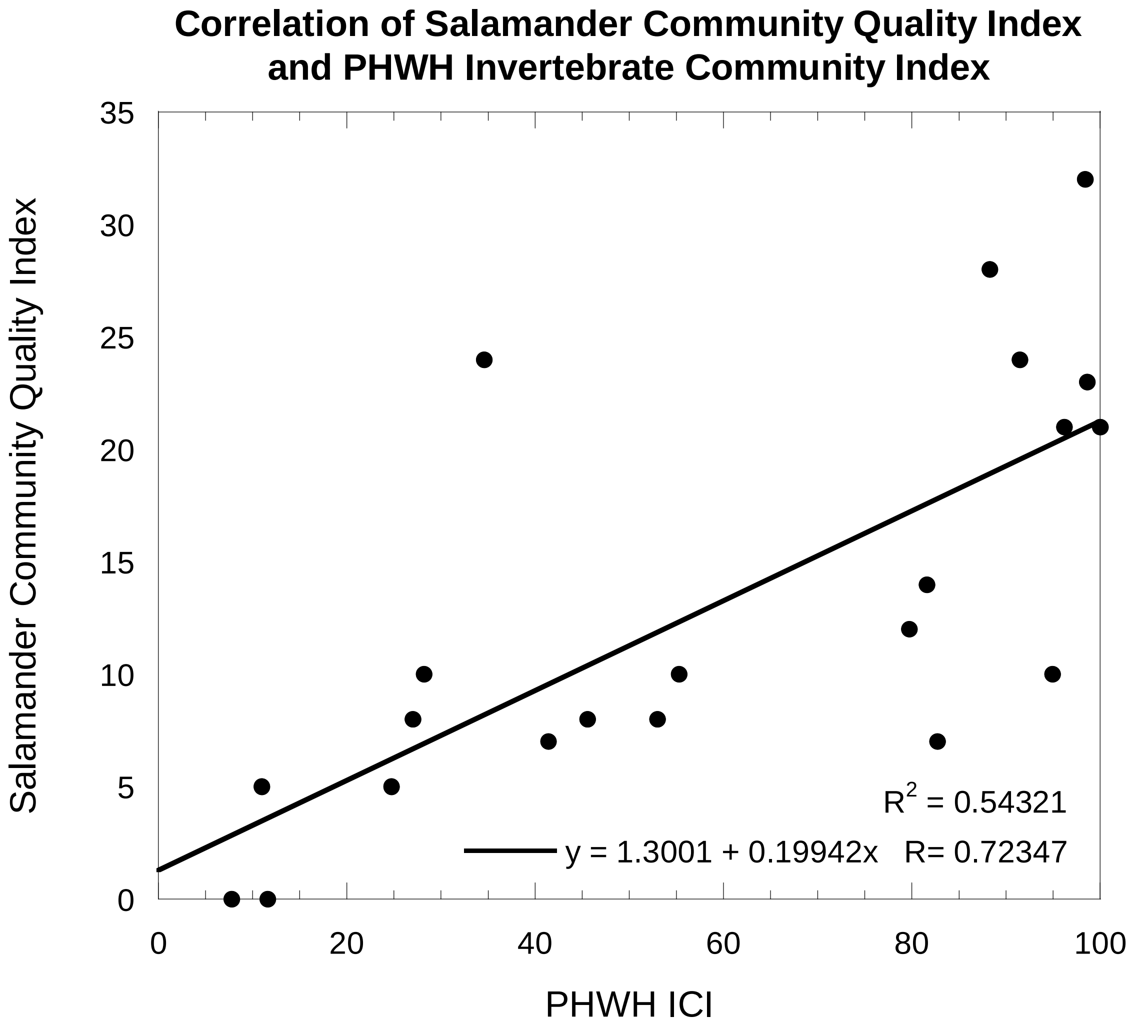

Figure 3.5. Correlation of the Salamander Community Quality Index and Headwater Macroinvertebrate Field Evaluation Index (HMFEI) for PHWH sites sampled in central, north-central, and northeast Ohio during spring to fall 2004-05.

DISCUSSION

Comparison of Salamander Sample Collections

Surber sample methods collected salamanders at the highest percentage of replicates among the quantitative methods with the leaf pack method second (Table 3.6). The bucket sample method had many more replicates, but salamnders were present in half as many as the Surber samples (USEPA 2006). However, the bucket samples had the highest number total counts of salamanders in the comparative samples. There were also more multiple age classes and/or different salamander taxa collected by the bucket sampling among the three different quantification methods. Salamanders were collected almost equally (presence) between riffle (erosional) and pool (depositional) bucket samples. The qualitative sampling methods (manually sampling the natural substrates) that were completed at each site covers a much larger area and, consequently, found salamanders at a higher percentage of sites (5 of 6 sites = 83%). However, even the qualitative substrate samples utilized less area than the 20 m^2 area sampled during the salamander VES survey utilized previously to help determine the PHWH class (OEPA 2002a). All data were compiled to determine the number of different salamander taxa collected and the total number of age classes present. Regardless, any salamander quality index developed will likely utilize primarily the PHWH VES salamander search protocol results with any additional incidental salamander collections by other means added to taxa totals and age class information. One limitationof the leaf pack method used for salamanders is that only those individuals captured with in the packs were enumerated. However, Davic and Skalski (2009) reported that 77% of 106 salamander larvae collected from the type of artificial leaf packs used in this study were found living under the bags, not within. Thus the data presented in Table 3.6 most likely underestimated the numbers of salamanders using the leaf packs in the sample site streams.

Salamander Index Development Selection Comparisons

Salamander indices 1 and 5 were the most difficult to classify and score, though index 1 had the highest correlation with HMFEI and HHEI (.448 and .273, respectively) (Figures 3.1 and 3.2). Index 5 had the second highest correlation with HMFEI and HHEI with 0.388 and 0.258, respectively (Figures 3.1 and 3.2). Distinguishing more than two larval classes in the field for indices 1 and 5 was very difficult and would cause more errors than garner additional information (Tables 3.1 and 3.5). Distinguishing older juveniles and young adult was also challenging which both indices 1 and 5 utilize (Tables 3.1 and 3.5). Indices 2 and 3 did not have enough range to adequately differentiate levels of quality (Table 3.7).

Salamander Index 4 was slightly easier to calculate because the only added requirement for additional quality scoring was observing greater than one larval class (i.e., observing two different size larvae). In salamander indices 1 and 5 the documentation of as many as three larval classes was very difficult.

Practically, any salamander community index needs to be adequately utilized by all collectors, with the understanding that most will not be herpetology specialists. Practically, indices 1 and 5 were difficult to be adequately utilized. Also in index 5 the identification between an older juvenile and a young adult was difficult and challenging. For these reasons Salamander Index 4 was slightly easier to implement and score than indices 1 and 5 (Table 3.7).

Salamander Index 4 differentiated the range of scoring differences enough to show quality ranges among the PHWH sample sites in the salamander index comparison study (Table 3.7). The range was zero to 27 with the top scores associated with sites that made sense ecologically and had a diverse community of macroinvertebrates. The top two index scores of 27 and 23 were documented at sites that were secluded and wooded reference habitats (NE2 and NE3). The three sites that scored 20 or 21 were protected wooded habitat or a site that demonstrated potential quality. Two sites (NE 5 and NE6) were protected watersheds with stable surroundings. The other similar score was documented in a ravine sandstone tributary to the Olentangy River (site C6). The higher score speaks to potential for continued quality despite the temporary sediment inputs from low density housing development upstream. Partly because of a rare red Salamander (*Pseudotriton ruber*) collected there at site C6, it has been protected as a preserve under local environmental authorities. The next scores of 14 were good but lower and likely related to some upper headwater agricultural influences. Both sites, NC1 and C9, were downstream from farming areas though both have extensive riparian corridors. One PHWH preserve reference site in upper Big Darby Creek, which had only been fallow for at most two growing seasons, still retained some apparent upstream agricultural influences which affected salamander diversity and robustness (scored a 9). Therefore, based on good scoring diversity, differentiation, and correlative ecological explanations the choice for the Salamander Community Quality Index was index 4.

Final PHWH Salamander Community Quality Index Scoring

Based on regional salamander distributions, regional collection possibilities, and number of salamander types actually collected at these higher-scoring reference sites, the highest maximum score for selected salamander index 4 (the Salamander Community Quality Index) was 45. The point scores in order for each section would be 20 and 4, 14 and 4, and 3 for a total of 45 (OEPA, 2002a). That would be the collection of two highly sensitive Class III salamanders with confirmed reproduction (e.g., spring and red Salamanders at 10 points pts. each = 20 pts.) with two different larval year classes each (2 pts. each = 4 pts.). The two moderately sensitive Class III species collected with verified reproduction would be the two-line and longtail Salamanders – the latter with two year larval classes present (for 7 pts. each = 14 pts.) with two year classes for both species (2 pts. each = 4 pts.). Then there would be three maximum points possible for the presence of a non CW species with verified reproduction (e.g., northern dusky Salamander). This combination equaled 45 points.

In an effort to include some density or total component, I added in a five point component called population and habitat stability. This component is the total collected of the predominant Class III salamander (almost always two-line salamanders) combined with a short habitat commentary: five points for robust population (>15) with stable habitat; three points for moderate population($\geq$ 10) with some good habitat; one point for rare ($\geq$ 5) with sparse habitat; and zero points for little or no salamanders present. With this modification the Salamander Community Quality Index (SCQI) totaled a possible 50 points (Table 3.8). The Salamander CQI scores were scored to 50 points and also scaled to 100% (Table 3.9). The scores ranged from 0-32 with a scale rating of 0%-64% for the highest Salamander Community Quality Index. Southerland et al. (2004) also found that the addition of some measure of salamander numbers present increased the predictability of their recommended Salamander Index of Biotic Integrity for Maryland streams.

Final Salamander Community Quality Index Correlation Comparisons

The final correlations of the Salamander Community Quality Index with the HMFEI (Headwater Macroinvertebrate Evaluation Index) and HHEI (Headwater Habitat Evaluation Index) site scores were similar to the other salamander index choices and improved slightly with the density scoring added into the

Salamander Community Quality Index	Points
(Combination of all Sampling Efforts)	
Highest TALLY SCORE FOR EACH SPECIES PRESENT	
Verified Reproduction of Highly Sensitive Class III CW Species	10 pts.
(Spring, Red, Mud, & Cave Salamanders)	
+ 2 pts. for each species with at least 2 yr. larval classes	≤ 8 pts.
Presence of Highly Sensitive CW Salamanders	8 pts.
(Spring, Red, Mud, & Cave Salamanders)	
Verified Reproduction of Moderately Sensitive CW Species	7 pts.
(Two-lined & Longtail Salamanders)	
NOTE- Longtail requires two larval yr. classes present	
+ 2 pts. for 2-Line & Longtail Salamanders with 2 yr. larval classes	≤ 4 pts.
Presence of Moderately Sensitive CW Species	
Two-lined Salamanders	5 pts.
Longtail Salamanders	4 pts.
Verified Reproduction of non CW Species	3 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
Presence of non CW Salamander Species	2 pts.
(Dusky, Four-Toed, or Streamside Salamanders)	
No Verified Presence of Salamanders	0 pts.
Population and Habitat Stability (add one choice to score)	
Robust population (≥15) with stable habitat	5 pts.
Moderate population (≥10) with some good habitat	3 pts.
Rare population (≥5) with sparse habitat	1 pt.
Little or no salamanders present (< 5)	0 pts.

Table 3.8. The final Salamander Community Quality Index selected from five comparative salamander indices developed while sampling selected PHWH stream sites in Ohio, spring to fall 2004-2005.

Site Name	Salamander Index 4	Class III PHWH Total Salamander Counts	Salamander Community Quality Index (of 50)	%
NC1	16	16	21	42
NE3	23	21	28	56
NE2	27	27	32	64
C5	9	7	10	20
C9	16	37	21	42
NE6	20	10	23	46
NC11	7	3	8	16
NC7	0	0	0	0
NC3	5	1	5	10
NC8	0	0	0	0
NC10	7	5	8	16
NC9	7	2	7	14
NE5	21	11	24	48
C2	7	2	7	14
NC2	9	31	14	28
C6	21	11	24	48
C8	5	2	5	10
C7	9	12	12	24
C3	9	8	10	20
NE1	7	6	8	16
NE4	7	10	10	20

Table 3.9. The Salamander Community Quality Index Totals for the PHWH salamander sample sites collected spring to fall 2004-2005 (after Salamander Index 4 was modified with Population and Habitat Stability score addition) and then converted to 100 scale.

Salamander Community Quality Index (Figure 3.3 and 3.4). The Salamander CQI was found to be marginally associated with the HMFEI (r^2=0.376) and HHEI (r^2=0.212) index scores (Figures 3.3 - 3.4). The lower correlations were due primarily to higher quality physical habitat PHWH sites with lower quality salamander diversity from past or continuing disturbances (range of condition sites) – less different taxa found than were there. However, the correlation coefficient was four times higher than the HHEI score and PHWH ICI correlation of 0.054. This was reasonable because the HHEI was developed to predict the presence of PHWH Class III bioindicator salamander species, and its metrics do not necessarily predict the presence of large numbers of cool-cold water adapted macroinvertebrate taxa. The higher HMFEI scores (30 – 40) with lower salamander index scores likely occurred for the same reason – past impacts with recovery where the macroinvertebrate community had recovered but the salamander community was still recovering or had not recovered due to isolation from new stock. Translocation of new salamander stock is possible if conditions improve locally (Thurow 1996).

One finding was that the Salamander Community Quality Index and the PHWH ICI were highly correlated with a correlation coefficient (r^2) of 0.543 (Figure 3.5). The correlation (r) of 0.723 was statistically significant at $P < 0.010$ (with critical value of 0.537, an alpha level of 0.01, and 20 degrees of freedom) (Sokal and Rohlf 1973). These invertebrate and salamander indices should be a complement to each other and showed the importance of dual organism sampling as at larger stream sites (OEPA 1987a,b, 2008).

The developed Salamander community Quality Index had similarities to the Stream Salamander IBI developed by Southerland et al. (2004). The Salamander CQI and the Stream Salamander IBI (Southerland et al. 2004) included number of species, numbers of individuals, and number of adults (SCQI - only if no larvae to score). Both indices were well associated with a benthic invertebrate IBI (or ICI), and were strongly associated with other common environmental variables like % forest, dissolved oxygen, embeddedness, and rocky substrates (Table 2.9) (Southerland et al. 2004). The main difference was my use of larval year classes of Class III and Class II salamanders to expand scoring and help differentiate quality, while Southerland et al. (2004) ended up not using larvae information.

Applicability of PHWH Salamander Community Quality Index

The final Salamander Community Quality Index for the PHWH sample sites appeared to be logical and appropriate. For instance, sites C2 and C5 were reference tributary sites in adjacent subwatersheds draining into Big Darby Creek headwaters, an exceptional quality PHWH reference stream that originated in Logan County (Figure 3.6). Site C2, the north tributary, scored similarly but lower than site C5 (7 to 10, respectively). Site C2 contained more former crop tillage area than site C5 with some residual effects from past agricultural activities. Site

C5, more wooded and with a higher HHEI, did score higher as expected (20% to 14%, respectively). Some salamander recovery should occur.

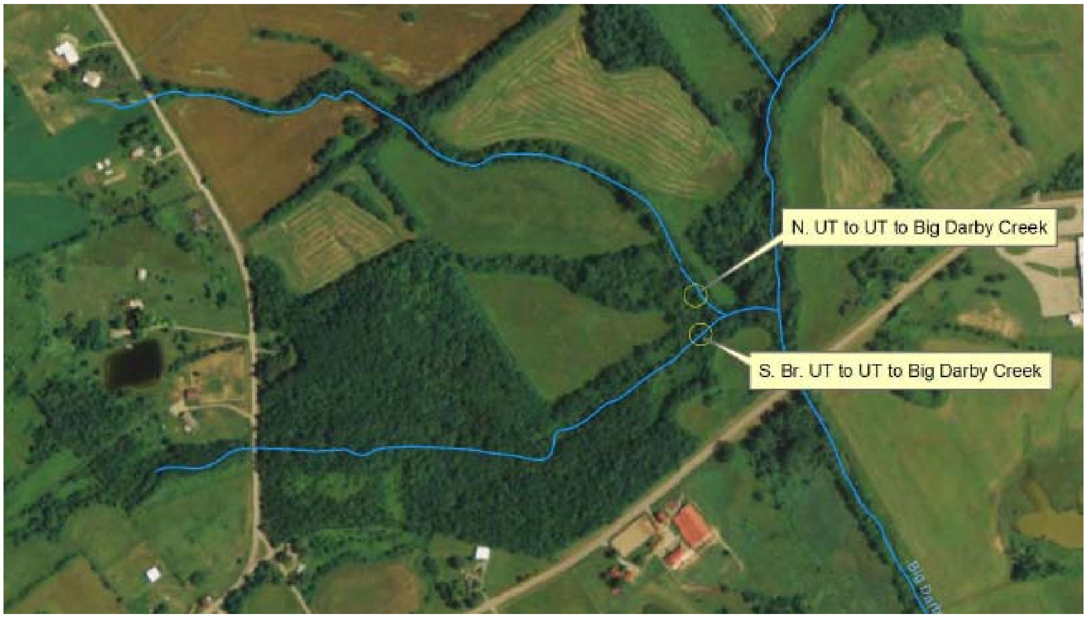

Figure 3.6. Aerial photo of subwatersheds for Primary Headwater Habitat (PHWH) sites C2 (north branch) and C5 (south branch) in the Big Darby Creek watershed, Logan County, Ohio sampled in fall 2005.

The PHWH site NC3, a tributary to Sugar Creek in the upper Sugar Creek watershed demonstrated that patchiness in land use affected stream quality. Woods surrounded the immediate sample site, but the riparian buffer thinned or disappeared in the upstream reach of the watershed (Figure 3.7). Hence the positive aspects of the riparian corridor were not as effective in limiting nonpoint source inputs into this primary headwater stream due to patchiness. The Salamander Community Quality Index of 10% was reflective of the nutrient and chemical inputs at this site (Table 3.9). Reestablishment of the riparian corridor upstream connecting the wooded reach would decrease nonpoint source input effects to the salamander community.

Figure 3.7. Aerial photo of Primary Headwater Habitat (PHWH) site NC3 (tributary to Sugar Creek) in Wayne County, northwest of Smithville, Ohio sampled fall 2005.

A strong association was documented in a correlation analysis between the PHWH ICI and the Salamander CQI ($r = 0.723$ which was significant at $P < 0.010$ with 20 df) (Figure 3.5) (Table 3.10) (Sokal and Rohlf 1973). The use of both invertebrate and vertebrate response indicators to determine the biotic

Site Name	PHWH ICI	Salamander Community Quality Index	Salamander Community Quality Index (%)
NC1	100	21	42
NE3	88.3	28	56
NE2	98.4	32	64
C5	94.9	10	20
C9	96.2	21	42
NE6	98.6	23	46
NC11	53.0	8	16
NC7	7.8	0	0
NC3	11.0	5	10
NC8	11.6	0	0
NC10	45.6	8	16
NC9	41.4	7	14
NE5	91.5	24	48
C2	82.7	7	14
NC2	81.6	14	28
C6	34.6	24	48
C8	24.7	5	10
C7	79.7	12	24
C3	28.2	10	20
NE1	27.0	8	16
NE4	55.3	10	20

Table 3.10. The PHWH ICI and the Salamander Community Quality Index (total score and percent scale to 100).

integrity of primary headwater streams was consistent with the OEPA approach for larger streams where both the fish IBI and macroinvertebrate ICI have been utilized (OEPA 1987a,b, 2008). This important association confirmed the importance of using two organism groups in the ecological assessment of PHWH streams.

CONCLUSION

Salamander Sample Collections Comparison

The 10-meter VES survey (OEPA, 2002a) was the primary salamander collection method with the bucket sampling method an incidental supplementary collection source. The bucket method captured the highest individual salamander counts in a sample with more multiple age classes of the three compared invertebrate quantitiative collection methods. The bucket method captured salamanders equally well in pools or riffle-run (lotic) reaches. Also macroinvertebrate qualitative sampling captured some incidental salamanders that added to salamander diversity totals. Calculations of a Salamander Community Quality Index using supplemental data from the bucket method agrees with the finding that data on macroinvertebrates using the bucket method provided the most robust PHWH ICI scores for predicting high quality Class III PHWH stream locations.

Salamander Index Development Selection Comparisons

Salamander index 4 was selected and was modified into the final recommended Salamander Community Quality Index (Tables 3.8-3.9). The Salamander Community Quality Index showed reasonable and consistent results to differentiate reference from impacted sites, as five of the top six scores were reference sites. The data indicated the Salamander Community Quality Index adequately ranked differing quality sites and illustrated ranges of higher quality and situations of degradation (Tables 3.8-3.9).

CHAPTER 4

DEVELOPMENT OF A PHWH COMMUNITY QUALITY INDEX FOR OHIO

PHWH Community Quality Index and Scoring

The independent Primary Headwater Habitat Invertebrate Community Index (PHWH ICI) and the Salamander Community Quality Index (SCQI) were added to get the sum of both which was the composite PHWH Community Quality Index (PHWH CQI) (Table 4.1). The PHWH Community Quality Index was scaled to 100 by dividing the sum total by 150 points and multiplying by 100 to get the PHWH Community Quality Index (in %) (Table 4.1).

The highest rated sites were appropriate and very similar to the quality ranking I had given the sample sites. I had ranked sites NE2 and NE6 (tributaries to Silver Creek in the Chagrin River basin) to have the best overall quality (Table 4.1).

A strong association was documented in a correlation analysis between portions of the PHWH Community Quality Index - the PHWH ICI and the Salamander CQI (r = 0.723; $P < 0.010$) (Figure 3.5). The use of both invertebrate and vertebrate response indicators to determine the biotic integrity of primary headwater streams is consistent with the OEPA approach for larger streams where both the fish IBI and macroinvertebrate ICI have been utilized (OEPA 1987b, 2008). This important association confirmed the importance of

Site Name	PHWH ICI	Salamander Community Quality Index	Salamander Community Quality Index (%)	PHWH Community Quality Index Total (150)	PHWH Community Quality Index %
NC1	100	21	42	121	80.7
NE3	88.3	28	56	116.3	77.5
NE2	98.4	32	64	130.4	86.9
C5	94.9	10	20	104.9	69.9
C9	96.2	21	42	117.2	78.1
NE6	98.6	23	46	121.6	81.1
NC11	53.0	8	16	61.0	40.7
NC7	7.8	0	0	7.8	5.2
NC3	11.0	5	10	16.0	10.7
NC8	11.6	0	0	11.6	7.7
NC10	45.6	8	16	53.6	35.7
NC9	41.4	7	14	48.4	32.3
NE5	91.5	24	48	115.5	77.0
C2	82.7	7	14	89.7	59.8
NC2	81.6	14	28	95.6	63.7
C6	34.6	24	48	58.6	39.1
C8	24.7	5	10	29.7	19.8
C7	79.7	12	24	91.7	61.1
C3	28.2	10	20	38.2	25.5
NE1	27.0	8	16	35.0	23.3
NE4	55.3	10	20	65.3	43.5

Table 4.1. The PHWH ICI and the Salamander Community Quality Index (total score and percent scale) with the combined PHWH Community Health Index (total and scaled to 100).

using two organism groups in the ecological assessment of PHWH streams – parts of the composite PHWH Community Quality Index.

Applicability of PHWH Community Quality Index

The last two profiled PHWH streams (C3, C6) were tributaries to the Olentangy River north of Columbus in Delaware County where intense suburbanization had taken place (Figure 4.1). Most of the watershed of PHWH

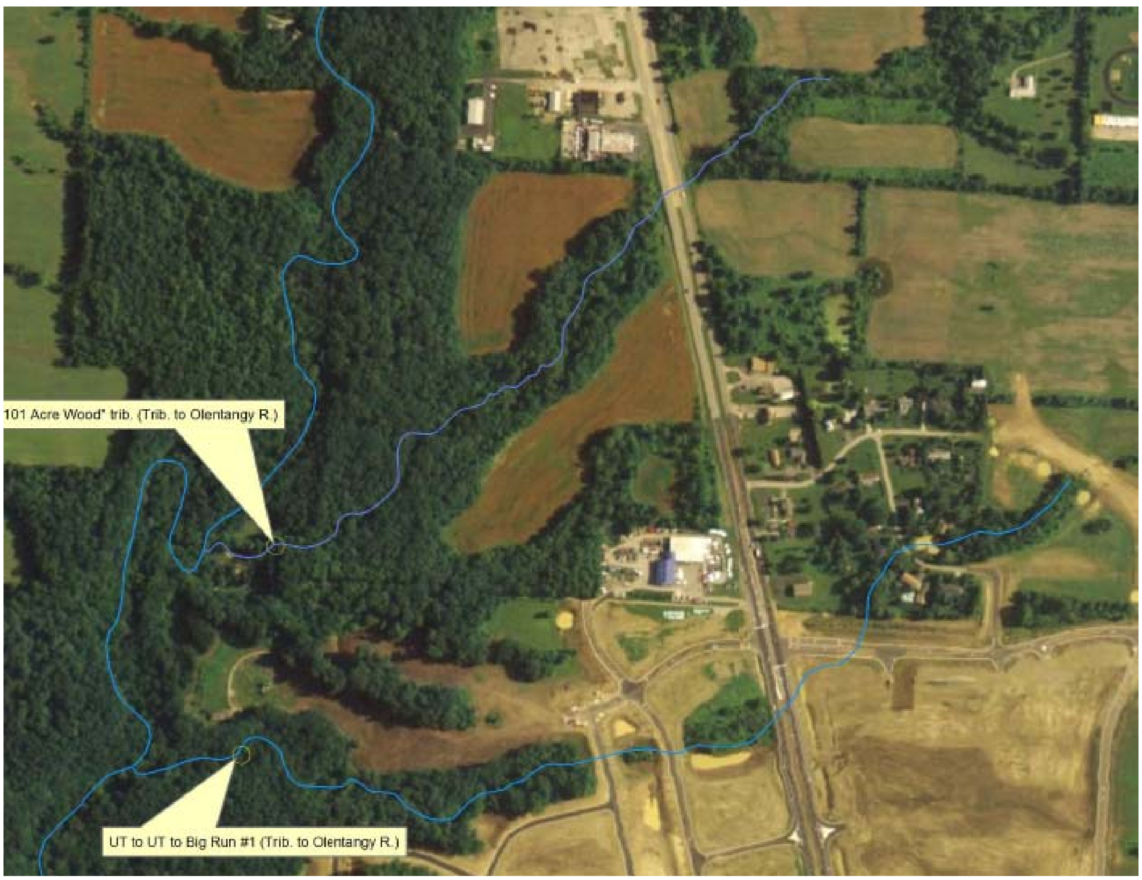

Figure 4.1. Aerial photo of Primary Headwater Habitat (PHWH) site C3 (tributary to Olentangy) and site C6 (Big Run tributary) in Delaware County, in northern edge of Columbus, Ohio, metropolitan area sampled spring to fall 2005.

sample site C3, a tributary to the Olentangy River, was stable woodland with a wide buffer. Upstream to the northeast its trace comes from the other side of the roadway with drainage connections to a commercial area and a high school complex upstream. Mayfly taxa were not collected and scored zeroes. Also the sensitive shredders had been replaced by more facultative taxa like isopods (*Lirceus* sp.). Both the PHWH ICI and Salamander Quality Index scored quite low (28.2 and 10, respectively). The combined PHWH Community Health Index was 38.2 or 25.5% (scaled to 100) (Table 4.1). Even though nearby stream site C6, an unnamed tributary to Big Run (another tributary to the Olentangy River), received nonpoint source runoff as quickly and was equally or more affected by the development inputs for a short time, the Salamander Community Quality Index of 48% showed far greater quality and greater diversity potential compared to PHWH site C3. The combined PHWH Community Health Index scores for the Big Run tributary (site C6) were 58.6 or 39.1%. The combined PHWH Community Quality Index scores for site C6 was 35% higher than that of site C3 (more urban runoff inputs) (Table 4.1). These biomonitoring tools should help with decisions on how to protect or manage certain streams. In this case, the lower watershed of the tributary to Big Run has been protected in a preserve (red Salamanders (*Pseudotriton ruber*) present) to maintain the still intact lower habitat which has since recovered from the temporary construction sedimentation effects.

CONCLUSION AND IMPLICATIONS

It was demonstrated that the developed PHWH Community Quality Index does function and can be used to prioritize restoration potential. It was also found that individual ICI and salamander indices can be used to illuminate patterns of effects in the biological communities and can be used to develop biomonitoring and protection strategies for PHWH streams.

The adoption of the PHWH Community Quality Index by the Ohio EPA for their biomonitoring program would have many useful implications. For new NPDES permit applications, data evaluated from small headwater streams now are restricted to the Headwater Habitat Evaluation Index (HHEI) and the Headwater Macroinvertebrate Field Evaluation Index (HMFEI) and sometimes a salamander survey for the purposes of stream classification. If PHWH indices were added to the assessment process, then once it was determined a Class III PHWH stream was present, data collected on salamanders as well as benthic macroinvertebrates would allow for calculation of index scores for the PHWH ICI and Salamander CQI and the composite PHWH CQI. This additional information would provide a baseline quality assessment that could be used to help with NPDES permit and other regulatory decisions such as required for Sections 404 and 401 of the Clean Water Act and for development of total maximum daily load (TMDL) targets (e.g., protection, monitoring, mitigation, restoration targets).

Where NPDES permitted dischargers might be located on PHWH streams, sampling to derive index scores (e.g., PHWH ICI, SCQI, and PHWH CQI) could be used to assure attainment or to document impacts. Such data could be collected by the Ohio EPA during surveys for larger streams (upstream of source, downstream from impact or input, and recovery further downstream). Data from these indices could be used to quantify stream community quality and health and to help better regulate the point source through discharge limits, TMDL targets.

Future Research

The indices developed for this study (PHWH ICI, Salamander CQI, and the composite PHWH CQI) have shown the quantify differences between reference and impacted Class III primary headwater streams. However, more sampling and data analysis needs to be done to further field validate these developed indices. Increased sample size at different times of the year would help identify the importance of seasonality when using these indices. For issues of restoration or baseline quality, it would be instructive to match sampling seasons for more direct comparisons with less extenuating factors. More sampling statewide is needed in different ecoregions of Ohio to investigate if the indices will work similarly in southwest and southeast areas of the state (different ecoregions than the Eastern Corn Belt Plain and Erie Ontario Lake Plain where it was developed). It also would be of interest to determine if the three indices developed for Ohio would be appropriate in surrounding states where general land characteristics are similar.

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APPENDIX

Additional Data

PHWH_Sites Local Name and Watershed	Site Name	Site No.	Quality Type	Narrative Quality	HMFEI	Latitude	Longitude
Izaak Walton Trib. ((Trib. to Cedar Run)	NC1	1	Reference	Exceptional	48	40.881800	-82.034800
Spring Brook (Bass Lake trib. to Chagrin R. mainstem)	NE3	2	Reference	Exceptional	36	41.552310	-81.234590
Alffelder Trib. (Trib. to Silver Cr.)	NE2	3	Reference	Exceptional	47	41.457450	-81.329280
South UT to UT to Big Darby Creek	C5	4	Reference	Exceptional	49	40.299283	-83.571167
UT to UT to Slate Run @ 3.67/0.30 (Slate Run Metropark)	C9	5	Reference	Exceptional	49.5	39.757200	-82.842200
West Woods Trib. (Trib. to Silver Cr. @ 4.07)	NE6	6	Reference	Exceptional	49	41.456100	-81.300800
Sugar Creek Trib. 24C("Old Rig" trib. site)	NC11	7	Range of Condition	Good	28	40.864830	-81.840675
Sugar CreekTrib. 8D (Lutheran Church trib. site)	NC7	8	Range of Condition	Very Poor - Poor	6	40.851697	-81.862351
Sugar Creek Trib. 20D ("Conservation Farm" trib. site)	NC3	9	Range of Condition	Poor - Fair	7	40.885628	-81.886807
Sugar Creek Trib. 8C (Baptist Church trib. site)	NC8	10	Range of Condition	Fair	21	40.859074	-81.867698
Sugar Creek Trib. 24D ("White House" trib. site)	NC10	11	Range of Condition	Marginally Good - Good	22	40.871598	-81.827279
Sugar Creek Trib. 8B (Smith front Barn trib. site)	NC9	12	Range of Condition	Good	28	40.860453	-81.864649
Trib. to Pierson Creek at Holden Arboretum	NE5	13	Reference	Very Good - Exceptional	42	41.612163	-81.369690
N. UT to UT to Big Darby Creek	C2	14	Reference	Exceptional	42	40.299400	-83.571367
Strock Trib. (Shuller Park)(Trib. to Little Killbuck Cr @ 2.0)	NC2	15	Reference	Very Good - Exceptional	30	40.821100	-82.021100
UT to UT to Big Run #1 (Trib. to Olentangy R.)	C6	16	Range of Condition	Fair - Marginally Good	21	40.203769	-83.038268
UT to UT to Olentangy R. (dst. Hyatts Rd. trib. site)	C8	17	Range of Condition	Marginally Good - Fair	27	40.213767	-83.036800
UT to Olentangy R. @ RM 14.09 (High Banks Metropark)	C7	18	Reference	Exceptional	46	40.148200	-83.031200
"101 Acre Wood" Trib. (Trib. to Olentangy R.)	C3	19	Range of Condition	Fair - Good	26	40.206167	-83.037783
Adams Park trib. (Trib. to Tinkers Cr.)	NE1	20	Range of Condition	Fair	21	41.341920	-81.481170
Spring Creek (Cuyahoga Valley National Park)	NE4	21	Range of Condition	Good to ~ Very Good	30	41.258360	-81.579310

Table A.1. Primary Headwater Habitat sample sites in Ohio sampled in spring and fall 2004-05 with local names and watershed, site names, site number, quality type (Reference or Range of Condition), narrative quality, Headwater Macroinvertebrate Field Evaluation Index scores (HMFEI), and latitude/longitude.

Primary Headwater Site Name	C2	C5	C7	C9
Headwater Macroinvertebrate Field Evaluation Index total	55	69	59	66
No. Qualitative Taxa	39	33	25	46
No. Quantitative Taxa	70	105	45	112
No. Quantitative Coldwater Taxa	18	23	13	20
Percent Quantitative Coldwater Taxa of Quantitative Taxa	25.7	21.9	28.9	17.9
Total No. Taxa (Quantitative + Qualitative Data)	83	112	52	128
Total No. Coldwater Taxa (Quantitative + Qualitative Data)	19	23	14	22
Percent Coldwater Taxa of Total Quantitative Count	16.5	13.2	16.7	53.4
No. Mayfly Taxa (Qualitative Data)	6	6	5	9
No. Mayfly Taxa (Qualitative & Quantitative Data)	6	10	7	12
No. Sensitive Mayflies (Qualitative & Quantitative Data)	6	8	5	9
Percent Sensitive Mayflies of Total Quantitative Count	12.5	13.3	21.1	10.5
Total No. Caddisfly Taxa (Qualitative & Quantitative Data)	10	14	6	11
Log (Sensitive Caddisfly Total Quantitative Count)	2.763	2.316	0.699	1.114
Log (Total Count Coldwater Caddisflies)	2.097	1.663	0.778	1.113
Total No. Stonefly Taxa (Qualitative & Quantitative Data)	2	5	5	7
Log (Total Count Stoneflies)	1.806	2.843	2.013	2.927
Log (Total Count Shredder Stoneflies)	1.8062	2.842	1.863	2.896
Total No. Ephemeroptera/Plecoptera/Trichoptera (EPT) Taxa	18	30	18	30
Total No. Sensitive EPT Taxa (Qualitative & Quantitative Data)	12	17	14	20
Total Count Sensitive EPT Taxa	1223	1312	289	1610
Square Root (Total Count Sensitive EPT Taxa)	34.97	36.22	17.00	40.13
Percent Sensitive EPT Taxa of Total Taxa	26.4	42.8	33.7	22.5
Arcsine Square Root (Percent Sensitive EPT Taxa of Total Taxa)	0.539	0.713	0.620	0.494
No. Sensitive Taxa (Qualitative & Quantitative Data)	48	58	31	56
Percent No. Sensitive Taxa of Total Taxa (Qualitative & Quant. data)	57.8	51.8	59.6	43.8
Percent Sensitive Taxa of Total Count	50.4	41.5	55.7	60.1
No. Intolerant Taxa (Qualitative & Quantitative Data)	5	9	5	12
Arcsine Square Root (Percent Intolerant Taxa of Total Sensitive Taxa)	0.3957	0.522	0.501	0.442
Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quant. data)	5.71	3.81	8.89	8.04
Percent Tolerant Taxa of Total Tolerant Taxa (Quantitative & Qualitative)	4.82	4.46	7.69	8.04
Percent Tolerant Taxa Of Total Count	17.8	4.99	5.25	3.54
Percent Facultative Taxa Of Total No. Taxa (Quantitative & Qualitative)	42.2	41.1	28.9	41.4
No. Midge Taxa (Quantitative & Qualitative data)	37	47	18	64
Log (No. Midge Taxa) (Quantitative & Qualitative data)	1.568	1.672	1.255	1.806
No. Sensitive Midge Taxa (Quantitative & Qualitative data)	19	27	11	32
Log (No. Sensitive Midge Taxa) (Quantitative & Qualitative data)	1.279	1.431	1.041	1.505
Arcsine Square Root (Percent Tolerant Midge Taxa of Midge Taxa) (Quantitative & Qualitative data)	0	0	0	0.218
Total Count Tolerant Midges	0	0	0	12
No. Coldwater Midges (Quantitative & Qualitative data)	10	14	6	12
No. Sensitive Taxa / No. Facultative Taxa (Quantitative & Qualitative)	1.37	1.26	2.07	1.06
No. Sensitive Taxa / No. Facultative Taxa (Total Count)	2.28	2.09	1.59	1.88
Log (No. Sensitive Taxa / No. Tolerant Taxa) (Total Count)	0.505	1.109	1.041	1.251
Sensitive Taxa / (Facultative + Tolerant Taxa)(Quant. & Qual.)	1.23	1.14	1.63	0.9
No. Sens. Taxa / No. (Facultative + Tolerant Taxa) (Total Count)	1.33	1.8	1.39	1.7
Square Root (No. Sens. Taxa / No. (Facultative + Tolerant Taxa))	1.154	1.341	1.178	1.305

continued

Table A.2 continued

Primary Headwater Site Name	C2	C5	C7	C9
Percent Non-Sensitive Gatherer-Collectors / Total Gatherer-Collectors	40.7	32.1	18.6	28.6
Sensitive Shredders / Non-Sensitive Shredders	71	702	74	5.35
Square Root (Sensitive Shredders / Non-Sensitive Shredders)	8.426	26.5	8.602	2.313
No. Predator Taxa (Quantitative & Qualitative data)	17	26	17	32

Table A.2. Summary invertebrate metric data (quantitative and qualitative) for Primary Headwater Habitat reference sample sites in central Ohio sampled in spring to fall 2004-05 for development of the Primary Headwater Habitat Invertebrate Community Index and the Salamander Community Quality Index. Abbreviation quantitative (quant.) and qualitative (qual.).

Primary Headwater Site Name	NE2	NE3	NE5	NE6
Headwater Macroinvertebrate Field Evaluation Index total	74	61	67	70
No. Qualitative Taxa	34	31	22	31
No. Quantitative Taxa	105	85	60	101
No. Quantitative Coldwater Taxa	33	29	22	36
Percent Quantitative Coldwater Taxa of Quantitative Taxa	31.4	34.1	36.7	35.6
Total No. Taxa (Quantitative + Qualitative Data)	110	91	63	107
Total No. Coldwater Taxa (Quantitative + Qualitative Data)	33	29	23	38
Percent Coldwater Taxa of Total Quantitative Count	37.6	49.6	32	54.3
No. Mayfly Taxa (Qualitative Data)	2	4	3	6
No. Mayfly Taxa (Qualitative & Quantitative Data)	7	5	6	7
No. Sensitive Mayflies (Qualitative & Quantitative Data)	7	4	5	6
Percent Sensitive Mayflies of Total Quantitative Count	16.7	2.14	25.5	10.4
Total No. Caddisfly Taxa (Qualitative & Quantitative Data)	18	14	8	15
Log (Sensitive Caddisfly Total Quantitative Count)	2.217	2.243	1.279	2.474
Log (Total Count Coldwater Caddisflies)	2.669	2.42	2.134	2.63
Total No. Stonefly Taxa (Qualitative & Quantitative Data)	5	5	6	7
Log (Total Count Stoneflies)	2.193	1.431	1.934	2.648
Log (Total Count Shredder Stoneflies)	2.127	1.362	1.716	2.607
Total No. Ephemeroptera/Plecoptera/Trichoptera (EPT) Taxa	30	23	19	30
Total No. Sensitive EPT Taxa (Qualitative & Quantitative Data)	22	19	18	22
Total Count Sensitive EPT Taxa	895	301	303	1091
Square Root (Total Count Sensitive EPT Taxa)	29.917	17.349	17.407	33.03
Percent Sensitive EPT Taxa of Total Taxa	32.4	6.4	39	32.1
ArcSine Square Root (Percent Sensitive EPT Taxa of Total Taxa)	0.606	0.256	0.674	0.603
No. Sensitive Taxa (Qualitative & Quantitative Data)	65	54	39	60
Percent No. Sensitive Taxa of Total Taxa (Qualitative & Quantitative Data)	59.1	59.3	61.9	56.1
Percent Sensitive Taxa of Total Count	66.2	65.6	66.7	56.6
No. Intolerant Taxa (Qualitative & Quantitative Data)	8	4	3	9
ArcSine Square Root (Percent Intolerant Taxa of Total Sensitive Taxa)	0.332	0.099	0.312	0.389
Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quantitative data)	5.71	7.06	5	7.92
Percent Tolerant Taxa of Total Tolerant Taxa (Quantitative & Qualitative data)	6.36	7.69	4.76	7.48
Percent Tolerant Taxa Of Total Count	8.56	11.8	0.77	1.83
Percent Facultative Taxa Of Total No. Taxa (Quantitative & Qualitative data)	32.7	33	33.3	32.7
No. Midge Taxa (Quantitative & Qualitative data)	50	40	13	46
Log (No. Midge Taxa) (Quantitative & Qualitative data)	1.699	1.602	1.114	1.663
No. Sensitive Midge Taxa (Quantitative & Qualitative data)	29	23	13	27
Log (No. Sensitive Midge Taxa) (Quantitative & Qualitative data)	1.462	1.362	1.114	1.431
ArcSine Square Root (Percent Tolerant Midge Taxa of Midge Taxa) (Quantitative & Qualitative data)	0.000	0.226	0.210	0.210
Total Count Tolerant Midges	0	2	1	10
No. Coldwater Midges (Quantitative & Qualitative data)	16	15	9	18
No. Sensitive Taxa / No. Facultative Taxa (Quantitative & Qualitative data)	1.81	1.8	1.86	1.71
No. Sensitive Taxa / No. Facultative Taxa (Total Count)	2.63	2.97	2.3	2.19
Log (No. Sensitive Taxa / No. Tolerant Taxa) (Total Count)	0.888	0.745	1.953	1.564
Sensitive Taxa / (Facultative + Tolerant Taxa)(Quantitative & Qualitative data)	1.51	1.46	1.63	1.4
No. Sens. Taxa / No. (Facultative + Tolerant Taxa) (Total Count)	1.96	1.94	2.24	2.07
Square Root (No. Sens. Taxa/No. (Facultative + Tolerant Taxa)) (Total Count)	1.401	1.392	1.497	1.437

continued

Table A.3 continued

Primary Headwater Site Name	NE2	NE3	NE5	NE6
Percent Non-Sensitive Gatherer-Collectors / Total Gatherer-Collectors	21.5	28.6	9.2	25.2
Sensitive Shredders / Non-Sensitive Shredders	29.4	10	53	68.2
Square Root (Sensitive Shredders / Non-Sensitive Shredders)	5.42	3.16	7.28	8.26
No. Predator Taxa (Quantitative & Qualitative data)	27	25	24	28

Table A.3. Summary invertebrate metric data (quantitative and qualitative) for Primary Headwater Habitat reference sample sites in northeast Ohio sampled in spring to fall 2004-05 for development of the Primary Headwater Habitat Invertebrate Community Index and the Salamander Community Quality Index.

Primary Headwater Site Name	NC1	NC2	NC3	NC7
Headwater Macroinvertebrate Field Evaluation Index total	67	48	23	12
No. Qualitative Taxa	33	21	4	7
No. Quantitative Taxa	101	55	31	37
No. Quantitative Coldwater Taxa	28	20	2	2
Percent Quantitative Coldwater Taxa of Quantitative Taxa	27.7	36	6.45	5.4
Total No. Taxa (Quantitative + Qualitative Data)	105	59	32	40
Total No. Coldwater Taxa (Quantitative + Qualitative Data)	29	20	2	2
Percent Coldwater Taxa of Total Quantitative Count	59.7	51	0.24	0.7
No. Mayfly Taxa (Qualitative Data)	7	3	0	0
No. Mayfly Taxa (Qualitative & Quantitative Data)	15	8	1	0
No. Sensitive Mayflies (Qualitative & Quantitative Data)	13	7	0	0
Percent Sensitive Mayflies of Total Quantitative Count	17.2	7.4	0	0
Total No. Caddisfly Taxa (Qualitative & Quantitative Data)	12	8	1	0
Log (Sensitive Caddisfly Total Quantitative Count)	2.204	1.544	-1	-1
Log (Total Count Coldwater Caddisflies)	2.097	2.111	-1	-1
Total No. Stonefly Taxa (Qualitative & Quantitative Data)	7	2	1	0
Log (Total Count Stoneflies)	2.919	2.114	0.699	-1
Log (Total Count Shredder Stoneflies)	2.897	1.851	0.699	-1
Total No. Ephemeroptera/Plecoptera/Trichoptera (EPT) Taxa	34	18	3	0
Total No. Sensitive EPT Taxa (Qualitative & Quantitative Data)	29	13	1	0
Total Count Sensitive EPT Taxa	1475	328	5	0
Square Root (Total Count Sensitive EPT Taxa)	38.406	18.111	2.236	0
Percent Sensitive EPT Taxa of Total Taxa	51.3	15	0.06	0
ArcSine Square Root (Percent Sensitive EPT Taxa of Total Taxa)	0.799	0.397	0.025	0
No. Sensitive Taxa (Qualitative & Quantitative Data)	54	37	3	2
Percent No. Sensitive Taxa of Total Taxa (Qualitative & Quantitative Data)	51.4	63	9.38	5
Percent Sensitive Taxa of Total Count	80.3	55	0.03	0.21
No. Intolerant Taxa (Qualitative & Quantitative Data)	13	10	0	0
ArcSine Square Root (Percent Intolerant Taxa of Total Sensitive Taxa)	0.7683	0.595	0	0
Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quantitative data)	3.96	3.6	32.3	40.5
Percent Tolerant Taxa of Total Tolerant Taxa (Quantitative & Qualitative data)	3.81	3.4	31.3	42.5
Percent Tolerant Taxa Of Total Count	0.66	2.5	93.9	94.2
Percent Facultative Taxa Of Total No. Taxa (Quantitative & Qualitative data)	34.3	37	59.4	50
No. Midge Taxa (Quantitative & Qualitative data)	50	18	8	2
Log (No. Midge Taxa) (Quantitative & Qualitative data)	1.699	1.255	0.903	0.301
No. Sensitive Midge Taxa (Quantitative & Qualitative data)	30	13	2	2
Log (No. Sensitive Midge Taxa) (Quantitative & Qualitative data)	1.477	1.114	0.018	0.018
ArcSine Square Root (Percent Tolerant Midge Taxa of Midge Taxa) (Quantitative & Qualitative data)	0	0	0.659	0.647
Total Count Tolerant Midges	0	0	18	44
No. Coldwater Midges (Quantitative & Qualitative data)	16	9	2	2
No. Sensitive Taxa / No. Facultative Taxa (Quantitative & Qualitative data)	1.5	1.7	0.16	0.1
No. Sensitive Taxa / No. Facultative Taxa (Total Count)	4.24	1.3	0.02	0.04
Log (No. Sensitive Taxa / No. Tolerant Taxa) (Total Count)	2.085	1.341	-3.046	-2.66
Sensitive Taxa / (Facultative + Tolerant Taxa)(Quantitative & Qualitative data)	1.35	1.5	0.08	0.05
No. Sens. Taxa / No. (Facultative + Tolerant Taxa) (Total Count)	4.09	1.2	0	0
Square Root(No. Sens. Taxa / (No. Facultative + Tolerant Taxa) (Total Count)	2.02	1.10	0.03	0.04

continued

Table A.4 continued

Primary Headwater Site Name	NC1	NC2	NC3	NC7
Percent Non-Sensitive Gatherer-Collectors / Total Gatherer-Collectors	8.39	18	100	99.7
Sensitive Shredders / Non-Sensitive Shredders	102	16	0.25	0
Square Root (Sensitive Shredders / Non-Sensitive Shredders)	10.112	4	0.5	0
No. Predator Taxa (Quantitative & Qualitative data)	25	18	8	9

Table A.4. Summary invertebrate metric data (quantitative and qualitative) for Primary Headwater Habitat reference sample sites (NC1 and NC2) and disturbed sites (NC3 and NC7) in north-central Ohio sampled in spring to fall 2004-05 for development of the Primary Headwater Habitat Invertebrate Community Index and the Salamander Community Quality Index.

Primary Headwater Site Name	NC8	NC9	NC10	NC11
Headwater Macroinvertebrate Field Evaluation Index total	27	42	29	38
No. Qualitative Taxa	16	17	17	14
No. Quantitative Taxa	37	43	45	42
No. Quantitative Coldwater Taxa	0	3	5	6
Percent Quantitative Coldwater Taxa of Quantitative Taxa	0	6.98	11.1	14
Total No. Taxa (Quantitative + Qualitative Data)	40	52	53	44
Total No. Coldwater Taxa (Quantitative + Qualitative Data)	0	3	7	6
Percent Coldwater Taxa of Total Quantitative Count	0	0.73	4.05	15
No. Mayfly Taxa (Qualitative Data)	2	3	1	3
No. Mayfly Taxa (Qualitative & Quantitative Data)	3	6	3	4
No. Sensitive Mayflies (Qualitative & Quantitative Data)	0	4	2	3
Percent Sensitive Mayflies of Total Quantitative Count	0	2	9.69	14.9
Total No. Caddisfly Taxa (Quantitative + Qualitative Data)	2	6	4	4
Log (Sensitive Caddisfly Total Quantitative Count)	-1	2.061	-1	2.025
Log (Total Count Coldwater Caddisflies)	-1	0.778	-1	-1
Total No. Stonefly Taxa (Quantitative + Qualitative Data)	0	1	1	0
Log (Total Count Stoneflies)	-1	2.489	0.954	-1
Log (Total Count Shredder Stoneflies)	-1	2.489	-1	-1
Total No. Ephemeroptera/Plecoptera/Trichoptera (EPT) Taxa	5	13	7	8
Total No. Sensitive EPT Taxa (Qualitative & Quantitative Data)	0	6	3	3
Total Count Sensitive EPT Taxa	0	445	100	491
Square Root (Total Count Sensitive EPT Taxa)	0	21.10	10	22.16
Percent Sensitive EPT Taxa of Total Taxa	0	40.5	10.7	19
ArcSine Square Root (Percent Sensitive EPT Taxa of Total Taxa)	0	0.690	0.332	0.452
No. Sensitive Taxa (Qualitative & Quantitative Data)	1	15	23	19
Percent No. Sensitive Taxa of Total Taxa (Qualitative & Quantitative Data)	2.5	28.9	43.4	43.2
Percent Sensitive Taxa of Total Count	0	13	28.1	45.2
No. Intolerant Taxa (Qualitative & Quantitative Data)	0	3	3	3
ArcSine Square Root (Percent Intolerant Taxa of Total Sensitive Taxa)	0	0.188	0.224	0.177
Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quantitative data)	43	16.3	15.6	11.9
Percent Tolerant Taxa of Total Tolerant Taxa (Quantitative & Qualitative data)	43	15.4	13.2	13.6
Percent Tolerant Taxa Of Total Count	91	25.6	18.9	6.32
Percent Facultative Taxa Of Total No. Taxa (Quantitative & Qualitative data)	55	53.9	39.6	45.5
No. Midge Taxa (Quantitative & Qualitative data)	8	14	28	18
Log (No. Midge Taxa) (Quantitative & Qualitative data)	0.903	1.146	1.447	1.255
No. Sensitive Midge Taxa (Quantitative & Qualitative data)	1	4	15	11
Log (No. Sensitive Midge Taxa) (Quantitative & Qualitative data)	0	0.602	1.176	1.041
ArcSine Square Root (Percent Tolerant Midge Taxa of Midge Taxa) (Quantitative & Qualitative data)	0.524	0.270	0.270	0.238
Total Count Tolerant Midges	26	10	9	0
No. Coldwater Midges (Quantitative & Qualitative data)	0	2	7	6
No. Sensitive Taxa / No. Facultative Taxa (Quantitative & Qualitative data)	0	0.54	1.1	0.95
No. Sensitive Taxa / No. Facultative Taxa (Total Count)	0	1.24	0.55	0.93
Log (No. Sensitive Taxa / No. Tolerant Taxa) (Total Count)	-3.398	0.206	0.183	0.854
Sensitive Taxa / (Facultative + Tolerant Taxa)(Quantitative & Qualitative data)	0	0.42	0.82	0.73
No. Sens. Taxa / No. (Facultative + Tolerant Taxa) (Total Count)	0	0.7	0.4	0.82
Square Root (No. Sens. Taxa / No. (Facultative + Tolerant Taxa)) (Total Count)	0.02	0.84	0.64	0.91

continued

Table A.5 continued

Primary Headwater Site Name	NC8	NC9	NC10	NC11
Percent Non-Sensitive Gatherer-Collectors / Total Gatherer-Collectors	100	97.6	37.1	29.8
Sensitive Shredders / Non-Sensitive Shredders	0	154	2.5	3
Square Root (Sensitive Shredders / Non-Sensitive Shredders)	0	12.41	1.581	1.732
No. Predator Taxa (Quantitative & Qualitative data)	10	11	12	11

Table A.5. Summary invertebrate metric data (quantitative and qualitative) for Primary Headwater Habitat disturbed sample sites in north-central Ohio sampled in spring to fall 2004-05 for development of the Primary Headwater Habitat Invertebrate Community Index and the Salamander Community Quality Index.

Primary Headwater Site Name	C3	C6	C8	NE1	NE4
Headwater Macroinvertebrate Field Evaluation Index total	31	40	30	14	42
No. Qualitative Taxa	21	13	18	20	20
No. Quantitative Taxa	26	48	39	37	28
No. Quantitative Coldwater Taxa	4	7	4	6	6
Percent Quantitative Coldwater Taxa of Quantitative Taxa	15.4	15	10	16.2	21.4
Total No. Taxa (Quantitative + Qualitative Data)	38	50	45	42	38
Total No. Coldwater Taxa (Quantitative + Qualitative Data)	6	7	5	9	9
Percent Coldwater Taxa of Total Quantitative Count	1	3.45	0.46	7.52	61.9
No. Mayfly Taxa (Qualitative Data)	1	1	1	0	1
No. Mayfly Taxa (Qualitative & Quantitative Data)	0	3	1	0	1
No. Sensitive Mayflies (Qualitative & Quantitative Data)	0	2	1	0	0
Percent Sensitive Mayflies of Total Quantitative Count	0	1.1	2.7	0	0
Total No. Caddisfly Taxa (Quantitative + Qualitative Data)	2	3	2	4	7
Log (Sensitive Caddisfly Total Quantitative Count)	-1	-1	-1	-1	0.60
Log (Total Count Coldwater Caddisflies)	0.778	0.602	-1	-1	1.20
Total No. Stonefly Taxa (Quantitative + Qualitative Data)	2	4	1	0	3
Log (Total Count Stoneflies)	1.079	1.431	0.903	-1	1.72
Log (Total Count Shredder Stoneflies)	0.845	0.778	0.903	-1	0
Total No. Ephemeroptera/Plecoptera/Trichoptera (EPT) Taxa	6	10	4	4	12
Total No. Sensitive EPT Taxa (Qualitative & Quantitative Data)	3	7	3	1	7
Total Count Sensitive EPT Taxa	12	34	44	0	57
Square Root (Total Count Sensitive EPT Taxa)	3.464	5.831	6.633	0	7.55
Percent Sensitive EPT Taxa of Total Taxa	1.2	5.2	3.4	0	38.8
ArcSine Square Root (Percent Sensitive EPT Taxa of Total Taxa)	0.110	0.230	0.184	0	0.67
No. Sensitive Taxa (Qualitative & Quantitative Data)	12	17	14	8	20
Percent No. Sensitive Taxa of Total Taxa (Qualitative & Quantitative Data)	31.6	34	31	19.1	52.6
Percent Sensitive Taxa of Total Count	1.9	14	7.2	24.8	50.3
No. Intolerant Taxa (Qualitative & Quantitative Data)	1	2	0	0	1
ArcSine Square Root (Percent Intolerant Taxa of Total Sensitive Taxa)	0	0.242	0	0	0
Percent Tolerant Taxa of Total Tolerant Individual Taxa (Quantitative data)	19.2	15	23	24.3	7.14
Percent Tolerant Taxa of Total Tolerant Taxa (Quantitative & Qualitative data)	15.8	14	29	21.4	7.89
Percent Tolerant Taxa Of Total Count	1.4	15	36	58.7	2.74
Percent Facultative Taxa Of Total No. Taxa (Quantitative & Qualitative data)	47.4	48	38	59.5	42.1
No. Midge Taxa (Quantitative & Qualitative data)	9	17	17	23	10
Log (No. Midge Taxa) (Quantitative & Qualitative data)	0.954	1.230	1.230	1.362	1
No. Sensitive Midge Taxa (Quantitative & Qualitative data)	3	6	8	8	5
Log (No. Sensitive Midge Taxa) (Quantitative & Qualitative data)	0.477	0.778	0.903	0.903	0.70
ArcSine Square Root (Percent Tolerant Midge Taxa of Midge Taxa) (Quantitative & Qualitative data)	0.491	0.245	0.350	0.299	0
Total Count Tolerant Midges	2	3	17	18	0
No. Coldwater Midges (Quantitative & Qualitative data)	4	5	4	8	4
No. Sensitive Taxa / No. Facultative Taxa (Quantitative & Qualitative data)	0.67	0.7	0.8	0.32	1.25
No. Sensitive Taxa / No. Facultative Taxa (Total Count)	0.03	0.2	0.1	1.5	1.07
Log (No. Sensitive Taxa / No. Tolerant Taxa) (Total Count)	0.301	-0.04	-0.67	-0.37	1.27
Sensitive Taxa / (Facultative + Tolerant Taxa)(Quantitative & Qualitative data)	0.5	0.6	0.5	0.24	1.05
No. Sens. Taxa / No. (Facultative + Tolerant Taxa) (Total Count)	0.03	0.2	0.1	0.33	1.01
Square Root (No. Sens. Taxa / No. (Facultative+Tolerant Taxa) (Total Count)	0.170	0.395	0.290	0.574	1.01

continued

Table A.6 continued

Primary Headwater Site Name	C3	C6	C8	NE1	NE4
Percent Non-Sensitive Gatherer-Collectors / Total Gatherer-Collectors	90.7	74	86	70.9	40
Sensitive Shredders / Non-Sensitive Shredders	0.16	0.1	0.8	0	2
Square Root (Sensitive Shredders / Non-Sensitive Shredders)	0.4	0.245	0.883	0	1.414
No. Predator Taxa (Quantitative & Qualitative data)	10	9	10	10	14

Table A.6. Summary invertebrate metric data (quantitative and qualitative) for Primary Headwater Habitat disturbed sample sites in central and northeast Ohio sampled in spring to fall 2004-05 for development of the Primary Headwater Habitat Invertebrate Community Index and the Salamander Community Quality Index.

Site Name	C2	C5	C7	C9	C3	C6	C8
AREA (km.^{2})	266.3	358.8	522.8	515.3	715.6	713.5	620.1
% Open Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Developed Open Space	6.1	13.7	6.4	5.6	25.32	7.3	9.9
% Low Intensity Residential	0.0	0.8	7.43	0.7	13.7	8.0	2.87
% Middle Intensity Residential	0.0	0.0	2.24	0.0	7.8	1.6	0.28
% High Intensity Residential	0.0	0.0	0.0	0.0	5.42	0.0	0.0
% Deciduous Forest	19.7	34.0	58.4	58.8	23.2	21.8	31.75
% Evergreen Forest	0.0	0.0	0.0	6.7	0.0	0.0	0.0
% Mixed Forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Scrub Shrub	0.0	0.0	0.0	4.2	0.0	1.2	0.0
% Grass Herbs	0.0	0.0	1.7	2.8	3.53	2.1	1.0
% Pasture Hay	29.8	39.1	23.83	11.2	4.91	27.0	25.6
% Cropland	44.4	12.4	0.0	10.0	16.12	31.0	28.6
% Wooded Wetland	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total % Forest	19.7	34.0	58.4	65.5	23.2	21.8	31.8
% Impervious Surface	0.61	1.65	4.70	0.81	17.28	4.57	2.18

Table A.7. Land Use environmental variable totals estimated by using GIS spatial analysis from the 2001 National Land Cover Data (NLCD 2001) for Primary Headwater reference sites (C2-C9) and disturbed sites (C3-C8) in central Ohio sampled spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development.

Site Name	NC1	NC2	NC3	NC7	NC8	NC9	NC10	NC11
AREA (km.^{2})	1511	204	1178	373	1439	1588	1151	2630
% Open Water	0.0	0.0	0.0	0.0	0.7	0.6	0.0	0.2
% Developed Open Space	4.83	0.0	4.6	6.1	12.4	13.2	3.3	6.2
% Low Intensity Residential	0.73	0.0	3.4	1.2	17.2	18.6	2.8	3.5
% Middle Intensity Residential	0.3	0.0	0.1	0.0	0.2	0.2	0.0	0.0
% High Intensity Residential	0.0	0.0	0.0	0.0	0.8	1.2	0.0	0.1
% Deciduous Forest	20.5	74.3	6.8	0.0	0.0	0.0	3.1	9.6
% Evergreen Forest	5.0	16.8	0.0	0.0	0.0	0.0	0.0	0.0
% Mixed Forest	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Scrub Shrub	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
% Grass Herbs	0.0	4.0	0.7	0.0	0.0	0.0	0.0	0.4
% Pasture Hay	11.2	4.9	32.2	0.0	0.0	0.0	0.0	10.4
% Cropland	56.94	0.0	51.1	92.7	68.7	66.2	90.8	69.2
% Wooded Wetland	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.4
Total % Forest	26.0	91.1	6.8	0.0	0.0	0.0	3.1	9.6
% Impervious Surface	0.93	0.00	1.72	1.03	8.11	9.04	1.31	1.94

Table A.8. Land Use environmental variable totals estimated by using GIS spatial analysis from the 2001 National Land Cover Data (NLCD 2001) for Primary Headwater reference sites (NC1-C2) and disturbed sites (NC3-NC11) in north-central Ohio sampled spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development.

Site Name	NE2	NE3	NE5	NE6	NE1	NE4
AREA (km.^{2})	1514.0	667.3	358.8	132.2	330.9	530.0
% Open Water	0.0	0.0	0.0	0.0	0.0	0.0
% Developed Open Space	20.7	41.3	13.7	0.0	59.5	6.45
% Low Intensity Residential	9.8	6.7	0.8	0.0	39.1	0.0
% Middle Intensity Residential	2.25	0.0	0.0	0.0	0.0	0.0
% High Intensity Residential	0.53	0.0	0.0	0.0	0.0	0.0
% Deciduous Forest	51.04	34.05	34.0	87.1	1.4	59.0
% Evergreen Forest	0.0	1.7	0.0	12.9	0.0	0.0
% Mixed Forest	0.24	0.0	0.0	0.0	0.0	0.0
% Scrub Shrub	0.0	0.0	0.0	0.0	0.0	0.0
% Grass Herbs	3.74	14.1	0.0	0.0	0.0	0.0
% Pasture Hay	2.2	2.15	39.1	0.0	0.0	0.0
% Cropland	9.5	0.0	12.4	0.0	0.0	30.95
% Wooded Wetland	0.0	0.0	0.0	0.0	0.0	3.6
Total % Forest	51.3	35.8	34.0	100	1.4	59.0
% Impervious Surface	7.44	6.48	1.65	0.00	19.64	0.65

Table A.9. Land Use environmental variable totals estimated by using GIS spatial analysis from the 2001 National Land Cover Data (NLCD 2001) for Primary Headwater reference sites (NE2-NE6) and disturbed sites (NE1, NE4) in northeast Ohio sampled spring to fall 2004-05 for Primary Headwater Habitat Invertebrate Community Index development.

Metric Names	Metric Names
Headwater Macroinvertebrate Field Evaluation Index	% Coldwater Caddisfly Taxa (Quantitative data)
Headwater Macroinvertebrate Field Evaluation Index total	Relative Density Coldwater Caddisfly Taxa (per m^2)
Quantitative Count Totals	% Coldwater Caddisflies of Total Caddisflies
Relative Density	% Facultative Caddisfly Taxa (Quantitative data)
Number Qualitative Taxa	Relative Density Facultative Caddisfly Taxa (per m^2)
No. Coldwater Taxa (Qualitative data)	% Facultative Caddisflies of Total Caddisflies
% Coldwater Taxa (Qualitative data)	No. Stonefly Taxa (Qualitative data)
No. Quantitative Taxa	No. Stonefly Taxa (Quantitative data)
No. Quantitative Coldwater Taxa (individual taxa)	Total No. Stonefly Taxa (Qualitative + Quantitative data)
Quantitative % Coldwater Taxa (individual taxa)	% Stoneflies (Quantitative data)
Quantitative Count Total Coldwater Taxa	Relative Density Stoneflies (per m^2)
Quantitative Count Total % Coldwater Taxa	% Coldwater Stoneflies (Quanitative data)
Total No Taxa (Quantitative + Qualitative data)	Relative Density Coldwater Stoneflies (per m2)
Total No. Coldwater Taxa (Quantitative + Qualitative)	% Coldwater Stoneflies of Total Stoneflies
Total % Coldwater Taxa (individual taxa)	No. Sensitive Stoneflies (Qualitative data)
No. Qualitative Mayfly Taxa	No. Sensitive Stoneflies (Quantitative data)
No. Sensitive Mayfly Taxa (Qualitative data)	Total No. Sensitive Stonefly Taxa (Qualitative + Quant.)
No. Sensitive Mayfly Taxa (Quantitative data)	Count Total Sens Caddisflies (Quantitative data)
Total No. Sensitive Mayflies (Quantitative + Qualitative)	Relative Density Sensitive Stoneflies (per m^2)
Total Count Sensitive Mayflies (Quantitative)	% Sens Stoneflies (Quantitative data)
Relative Density Sensitive Mayflies (Quant.) (per m^2)	% Sens Stoneflies of Total Stoneflies
% Sensitive Mayflies (Quantitative data)	% Shredder Stoneflies (Quantitative data)
% Total Mayflies (Quantitative data)	Relative Density Shredder Stoneflies (per m^2)
% Facultative Mayflies (Quantitative data)	% Shredder Stoneflies of Total Stoneflies
Relative Density Facultative Mayflies (per m^2)	% Predator Stoneflies (Quantitative data)
% Facultative Baetid Mayflies of Total Mayflies	Relative Density Predator Stoneflies (per m^2)
% Heptageneid + Ephemerellid Mayflies (Quantitative)	% Predator Stoneflies of Total Stoneflies
Relative Density Heptageneid + Ephemerellid Mayflies	No. Qualitative EPT Taxa
% Heptageneid+Ephemerellid Mayflies / Mayflies (Quant.)	No. Quantitative EPT Taxa
% Baetid + Lotic Mayflies (Quantitative)	Total No. EPT Taxa
Relative Density Baetid + Lotic Mayflies (per m^2)	Quantitative Count EPT Taxa
% Baetid + Lotic Mayflies of All Mayflies (Quantitative)	Relative Density EPT (per m^2)
No. Caddisfly Taxa (Qualitative data)	% EPT taxa of Total Count
Total No. Caddisfly Taxa (Quantitative data)	No. Sensitive EPT Taxa (Qualitative data)
Total No. Caddisfly Taxa (Qualitative + Quantitative data)	No. Sensitive EPT Taxa (Quantitative data)
% Caddisfly Taxa of Total Count (Quantitative data)	Total No. Sensitive EPT Taxa (Qualitative + Quantitative)
Relative Density Total Caddisfly Taxa (per m^2)	Total Count Sensitive EPT Taxa
No. Sensitive Caddisfly Taxa (Qualitative data)	Relative Density Sensitive EPT Taxa (per m^2)
No. Sensitive Caddisfly Taxa (Qualitative + Quantitative)	% Sensitive EPT Taxa fo Total Count
Total Count Sensitive Caddisflies (Quantitative)	No. Sensitive Taxa (Qualitative data)
% Sens Caddisfly Taxa (Quantitative data)	No. Sensitive Taxa (Quantitative data)
Relative Density Sensitive Caddisfly Taxa (per m^2)	No. Sensitive Taxa (Qualitative + Quantitative data)
% Sensitive Caddisflies of Total Caddisflies	% No. Sensitive Taxa of Total Qualitative Taxa
Total No. Coldwater Caddisfly Taxa (Quantitative data)	% No. Sensitive Taxa of Total No. Taxa (Quant. data)
Total No. Coldwater Caddisfly Taxa (Qualitative + Quant.)	% No. Sensitive Taxa of Total No. Taxa (Qual. + Quant.)

continued

Table A.10 continued

Metric Names	Metric Names
Total Count Sensitive Taxa	% Sens Midge Taxa /Total Midge Taxa (Qual. + Quant.)
Relative Density Sensitive Taxa (per m^2)	Total Count Sensitive Midges
% Sens Taxa of Total Taxa Count	Relative Density Sensitive Midges (per m^2)
No. Intolerant Taxa (Qualitative data)	% Sensitive Midges of Total Midges
No. Intolerant Taxa (Quantitative data)	% Sensitive Midges of Total Sensitive Taxa Count
No. Intolerant Taxa Qualitative + Quantitative data)	% Count Sensitive Midges of Total Sample Count
% No. Intolerant Taxa of No. Qualitative Taxa	No. Intolerant Midge Taxa (Qualitative data)
% No. Intolerant Taxa of No. Taxa (Quant. data only)	No. Intolerant Midge Taxa (Quantitative data)
% No. I Taxa of No. Taxa (Qualitative + Quantitative data)	No. Intolerant Midge Taxa (Qualitative + Quantitative)
Total Count Intolerant Individuals	% No. Intolerant Midge Taxa of No. Qual. Midge Taxa
Relative Density Intolerant Individuals (per m^2)	% No. Intolerant Midge Taxa of No. Quant. Midge Taxa
% Intolerant Individuals of Total Count	% No. Intolerant Midge Taxa / Midge Taxa (Qual.+ Quant.)
% Intolerant Individuals of Total Sensitive Taxa	Total Count Intolerant Midges
Total No. Tolerant Taxa (Qualitative data)	Relative Density Intolerant Midges (per m^2)
Total No. Tolerant Taxa (Quantitative data)	% Intolerant Midges of Total Midges
Total No. Tolerant Taxa (Qualitative + Quantitative data)	% Intolerant Midges of Total Sensitive Midges
% Tolerant Taxa Of Total No. Qualitative Taxa	% Intolerant Midges of Total Sensitive Taxa
% Tolerant Taxa Of Total No. Taxa (Quantitative data)	% Intolerant Midges of Total Count
% Tolerant Taxa Of Total No. Taxa (Qual. + Quant. data)	No. Tolerant Midge Taxa (Qualitative data)
Total Count Tolerant Taxa	No. Tolerant Midge Taxa (Quantitative data)
Relative Density Tolerant Taxa (per m^2)	No. Tolerant Midge Taxa (Qualitative + Quantitative data)
% Tolerant Taxa Of Total Count	% No. Tol. Midge Taxa of Total Midge Taxa (Qual. data)
Total No. Facultative Taxa (Qualitative data)	% No. Tol. Midge Taxa of Total Midge Taxa (Quant. data)
Total No. Facultative Taxa (Quantitative data)	% No. Tol. Midge Taxa of Total Midge Taxa (Qual.+ Quant.)
Total No. Facultative Taxa (Qual + Quant. data)	Total Count Tolerant Midges (per m^2)
% Facultative Taxa Of Total No. Qualitative Taxa	Relative Density Tolerant Midges (per m^2)
% Facultative Taxa Of Total No. Quantitative Taxa	% Count Tolerant Midges of Total Midges
% Facultative Taxa Of Total No. Taxa (Qual.+ Quant.)	% Count Tolerant Midges of Total Tolerant Taxa
Total Count Facultative Taxa	% Count Tolerant Midges of Total Count
Relative Density Facultative Taxa (per m^2)	No. Facultative Midge Taxa (Qualitative data)
% Facultative Taxa Of Total Count	No. Facultative Midge Taxa (Quantitative data)
No. Midge Taxa (Qualitative data)	No. Facultative Midge Taxa (Qualitative + Quantitative)
No. Midge Taxa (Quantitative data)	% No. Facultative Midge Taxa / Total Midge Taxa (Qual.)
No. Midge Taxa (Qualitative + Quantitative data)	% No. Facultative Midge Taxa / Total Midge Taxa (Quant.)
% No. Midge Taxa of Total No. Taxa (Qualitative data)	% No. Facultative Midge Taxa/Total Midge Taxa (Qual + Quant)
% No. Midge Taxa of Total No. Taxa (Quant. data)	Total Count Facultative Midges
% No. Midge Taxa of Total No. Taxa (Qual. + Quant.)	Relative Density Facultative Midges (per m^2)
Count Total Midges	% Count Facultative Midges of Total Midges
Relative Density Total Midges (per m^2)	% Count Facultative Midges of Total Facultative Taxa
% Midges of Total Count	% Count Facultative Midges of Total Sample Count
No. Sensitive Midge Taxa (Qualitative data)	No. Coldwater Midges (Qualitative data)
No. Sensitive Midge Taxa (Quantitative data)	No. Coldwater Midges (Quantitative data)
No. Sensitive Midge Taxa (Qual. + Quant. data)	No. Coldwater Midges (Qualitative + Quantitative data)
% No. Sensitive Midge Taxa of Total Midge Taxa (Qual.)	% No. Coldwater Midge Taxa of Total Midge Taxa (Qual.)
% No. Sensitive Midge Taxa of Total Midge Taxa (Quant.)	% No. Coldwater Midge Taxa of Total Midge Taxa (Quant.)

continued

Table A.10 continued

Metric Names	Metric Names
% No. Coldwater Midge Taxa / Total Midge Taxa	% *Rheotanytarsus* sp. / Total Filterer Collector Individuals
(Qualitative + Quantitative)	No. Gatherer Collector Taxa (Qualitative data)
Total Count Coldwater Midges	No. Gatherer Collector Taxa (Quantitative data)
Relative Density Count Coldwater Midges (per m^2)	% No. Gatherer Collector Taxa / Total Taxa (Qual.+ Quant.)
% Count Coldwater Midges of Total Midges	Total Count Gatherer Collector Individuals (Quant. data)
% Count Coldwater Midges of Total Coldwater Taxa	Relative Density Gatherer Collector Individuals (per m^2).
% Count Coldwater Midges of Total Count	% Gatherer Collectors of Total Count
No. Sensitive Taxa / No. Facultative Taxa (Qual. + Quant.)	No. Sensitive Taxa / (No. Facultative + Tolerant Taxa)
Sensitive Taxa / No. Facultative Taxa (Total Count)	(Qualitative + Quantitative)
No. Facultative Taxa / No. Sensitive Taxa (Qual. + Quant.)	No. Sensitive Taxa / (No. Facultative + Tolerant Taxa)
Facultative Taxa / No. Sens. Taxa (Total Count)	(Total Count)
No. Sensitive Taxa / No. Tolerant Taxa (Qual.+ Quant.)	No. Filterer Collector Taxa (Qualitative data)
Sensitive Taxa / No. Tolerant Taxa (Total Count)	No. Filterer Collector Taxa (Qual. + Quant. data)
Tolerant Taxa / No. Sensitive Taxa (Qual. + Quant. data)	% No. Filterer Collector Taxa/Total Taxa (Qual.+ Quant.)
Tolerant Taxa / No. Sensitive Taxa (Total Count)	Total Count Filterer Collector Individuals (Quant. data)
No. Facultative Taxa / No. Tolerant Taxa (Qual.+ Quant.)	Relative Density Filterer Collector Individuals (per m^2)
No. Facultative Taxa / No. Tolerant Taxa (Total Count)	% Filterer Collectors of Total Count
No. Tolerant Taxa / No. Facultative Taxa (Qual. + Quant.)	Total Count Non-Sensitive Filterer Collector Individuals
No. Tolerant Taxa / No. Facultative Taxa (Total Count)	Sensitive Filterer Collectors / Non-Sens. Filterer Collectors
No. Sens. Taxa / (No. Facultative + Tolerant Taxa)	% Non-Sensitive Filterer Collectors / Total Count
(Qualitative + Quantitative data)	% Non-Sensitive Filterer Collectors / Total Filterer Collectors
No. Sensitive Taxa / (No. Facultative + Tolerant Taxa)	Total Count Non-Sensitive Filterer Collector Caddisflies
(Total Count)	% Non-Sensitive Filterer Collector Caddisflies / Total Count
No. Filterer Collector Taxa (Qualitative data)	% Non-Sens. Filterer Collector Caddisflies/Filterer Collectors
No. Filterer Collector Taxa (Qual. + Quant. data)	Total Cnt. *Rheotanytarsus* sp. FC Midge
% No. Filterer Collector Taxa / Total Taxa (Qual.+ Quant.)	% *Rheotanytarsus* sp. / Total Count
Total Count Filterer Collector Individuals (Quant. data)	% *Rheotanytarsus* sp. / Total Filterer Collector Individuals
Relative Density Filterer Collector Individuals (per m^2)	No. Gatherer Collector Taxa (Qualitative data)
% Filterer Collectors of Total Count	No. Gatherer Collector Taxa (Quantitative data)
Total Count Non-Sensitive Filterer Collector Individuals	% No. Gatherer Collector Taxa / Total Taxa (Qual.+ Quant.)
Sensitive Filterer Collectors / Non-Sens. Filterer Collectors	Total Count Gatherer Collector Individuals (Quant. data)
% Non-Sensitive Filterer Collectors / Total Count	Relative Density Gatherer Collector Individuals (per m^2).
% Non-Sensitive Filterer Collectors / Total Filterer Collectors	% Gatherer Collectors of Total Count
Total Count Non-Sensitive Filterer Collector Caddisflies	Total Count Non-Sensitive Gatherer Collector Individuals
% Non-Sensitive Filterer Collector Caddisflies / Total Count	Sens. Gatherer Collectors/Non-Sens. Gatherer Collectors
% Non-Sens. Filterer Collector Caddisflies/Filterer Collectors	% Non-Sensitive Gatherer Collectors of Total Count
Total Count *Rheotanytarsus* sp. Filterer Collector Midge	% Non-Sens. Gatherer Collectors/Total Gatherer Collectors
% *Rheotanytarsus* sp. / Total Count	Total Count Non-Sensitive Gatherer Collector Midges

continued

Table A.10 continued

Metric Names	Metric Names
% Non-Sens. Gatherer Collector Midges of Total Count	% No. Shredder Taxa / Total Taxa (Qual. + Quant. data)
% Non-Sensitive Gatherer Collector Midges of Total Gatherer Collectors	Total Count Shredders (Quantitative data)
	Relative Density Shredder Individuals (per m^2)
Sensitive Gatherer Collector Midges / Non-Sensitive Gatherer Collector Midges	% Shredders of Total Count
	Sensitive Shredders / Non-Sensitive Shredders
Total Count *Polypedilum aviceps* & *Polypedilum albicorne*	Parasite Individuals / Quantitative Count Totals
No. *P. flavum* / *P. aviceps* & *P. Albicorne* (Total Count)	No. Predator Taxa (Qualitative data)
No. Scraper Collector Taxa (Qualitative data)	No. Predator Taxa (Qualitative + Quantitative data)
No. Scraper Collector Taxa (Qualitative + Quant. data)	No. Predator Taxa of Total No. Taxa (Qual. + Quant.)
% No. Scraper Collector Taxa of Total Taxa (Qual.+Quant.)	% Predators of Total Count
Total Count Scraper Collector Individuals	Total Count Sensitive Predators / Non-Sensitive Predators
Total Count Non-Sensitive Scraper Collectors	Total Count Sensitive Predators
Sens. Scraper Collectors / Non-Sens. Scraper Collectors	Total Count Non-Sensitive Predators
Relative Density Scraper Collectors (per m^2)	Total Count Predators
% Scraper Collectors of Total Count	Total Count *Polypedilum flavum* Midges
Sum (Facultative and Tolerant Filterer Collector, Gatherer Collector, and Scraper Collector groups)	% *Polypedilum flavum*/ Total Count
	% *Polypedilum flavum* / Total Count General Collectors
% (Facultative & Tolerant Filterer Collector, Gatherer Collector, and Scraper Collector groups) /Total Count	No. Midge Taxa (Tribe) (Qualitative data)
	No. Midge Taxa (Tribe) (Quantitative data)
No. Shredder Taxa (Qualitative data)	No. Midge Taxa (Tribe) (Qualitative + Quantitative data)
No. Shredder Taxa (Qualitative + Quantitative data)	% Midge Taxa (Tribe) of Total Taxa (Revised Count)

Table A.10. List of 266 initial invertebrate metrics (without transformations) for use in Primary Headwater Habitat Invertebrate Community Index development from reference and disturbed Primary Headwater Habitat sites in central, north-central, and northeast Ohio sampled in spring to fall 2004-05. Abbreviations used: quantitative (quant.), qualitative (qual.), sensitive (sensitive), and number (No.).

Site Name	Site No.	Class III Larval Salamanders Present				
		2-Line	Longtail (2 yr.)	Red	Mud	Spring
NC1	1	1	0	0	0	0
NE3	2	1	0	1	0	0
NE2	3	1	0	1	0	0
C5	4	1	0	0	0	0
C9	5	1	0	0	0	0
NE6	6	1	0	0	0	0
NC11	7	1	0	0	0	0
NC7	8	0	0	0	0	0
NC3	9	0	0	0	0	0
NC8	10	0	0	0	0	0
NC10	11	1	0	0	0	0
NC9	12	1	0	0	0	0
NE5	13	1	0	1	0	0
C2	14	1	0	0	0	0
NC2	15	1	0	0	0	0
C6	16	1	0	1	0	0
C8	17	0	0	0	0	0
C7	18	1	0	0	0	0
C3	19	1	0	0	0	0
NE1	20	1	0	0	0	0
NE4	21	1	0	0	0	0
		$\geq$ 2 Different Class III Larval Year Classes				
		2-Line	Longtail (2 yr.)	Red	Mud	Spring
NC1	1	1	0	0	0	0
NE3	2	1	0	1	0	0
NE2	3	1	0	0	0	0
C5	4	1	0	0	0	0
C9	5	1	0	0	0	0
NE6	6	1	0	0	0	0
NC11	7	0	0	0	0	0
NC7	8	0	0	0	0	0
NC3	9	0	0	0	0	0
NC8	10	0	0	0	0	0
NC10	11	0	0	0	0	0
NC9	12	0	0	0	0	0
NE5	13	1	0	0	0	0
C2	14	0	0	0	0	0
NC2	15	1	0	0	0	0
C6	16	1	0	0	0	0
C8	17	0	0	0	0	0
C7	18	1	0	0	0	0
C3	19	1	0	0	0	0
NE1	20	0	0	0	0	0
NE4	21	0	0	0	0	0

continued

Table A.11 continued

		No. of Class III Larvae				
		2-Line	Longtail	Red	Mud	Spring
NC1	1	7	NA	0	0	0
NE3	2	14	NA	5	0	0
NE2	3	17	NA	1	0	0
C5	4	6	NA	0	0	0
C9	5	30	NA	0	0	0
NE6	6	8	NA	0	0	0
NC11	7	2	NA	0	0	0
NC7	8	0	NA	0	0	0
NC3	9	0	NA	0	0	0
NC8	10	0	NA	0	0	0
NC10	11	1	NA	0	0	0
NC9	12	1	NA	0	0	0
NE5	13	5	NA	1	0	0
C2	14	1	NA	0	0	0
NC2	15	30	NA	0	0	0
C6	16	8	NA	1	0	0
C8	17	0	NA	0	0	0
C7	18	5	NA	0	0	0
C3	19	6	NA	0	0	0
NE1	20	5	NA	0	0	0
NE4	21	8	NA	0	0	0

		Class III Larval Relative Density (per m^2)					
		2-Line	Longtail	Red	Mud	Spring	Relative Density
NC1	1	0.44	NA	0.00	0	0	0.44
NE3	2	0.09	NA	0.03	0	0	0.12
NE2	3	0.71	NA	0.04	0	0	0.75
C5	4	0.65	NA	0.00	0	0	0.65
C9	5	2.92	NA	0.00	0	0	2.92
NE6	6	0.17	NA	0.00	0	0	0.17
NC11	7	0.07	NA	0.00	0	0	0.07
NC7	8	0.00	NA	0.00	0	0	0.00
NC3	9	0.00	NA	0.00	0	0	0.00
NC8	10	0.00	NA	0.00	0	0	0.00
NC10	11	0.03	NA	0.00	0	0	0.03
NC9	12	0.03	NA	0.00	0	0	0.03
NE5	13	0.23	NA	0.05	0	0	0.28
C2	14	0.10	NA	0.00	0	0	0.10
NC2	15	0.76	NA	0.00	0	0	0.76
C6	16	0.06	NA	0.01	0	0	0.07
C8	17	0.00	NA	0.00	0	0	0.00
C7	18	0.20	NA	0.00	0	0	0.20
C3	19	0.25	NA	0.00	0	0	0.25
NE1	20	0.83	NA	0.00	0	0	0.83
NE4	21	0.37	NA	0.00	0	0	0.37

continued

Table A.11 continued

		Class III Juvenile/Adult Salamanders Present				
		2-Line	Longtail	Red	Mud	Spring
NC1	1	1	NA	0	0	0
NE3	2	1	NA	0	0	0
NE2	3	1	NA	0	0	0
C5	4	0	NA	0	0	0
C9	5	0	NA	0	0	0
NE6	6	0	NA	1	0	0
NC11	7	0	NA	0	0	0
NC7	8	0	NA	0	0	0
NC3	9	0	NA	0	0	0
NC8	10	0	NA	0	0	0
NC10	11	0	NA	0	0	0
NC9	12	1	NA	0	0	0
NE5	13	1	NA	1	0	0
C2	14	1	NA	0	0	0
NC2	15	1	NA	0	0	0
C6	16	0	NA	0	0	0
C8	17	0	NA	0	0	0
C7	18	0	NA	0	0	0
C3	19	0	NA	0	0	0
NE1	20	1	NA	0	0	0
NE4	21	1	NA	0	0	0
		Class III Juvenile Salamanders Present				
		2-Line	Longtail	Red	Mud	Spring
NC1	1	1	NA	0	0	0
NE3	2	0	NA	0	0	0
NE2	3	0	NA	0	0	0
C5	4	1	NA	0	0	0
C9	5	1	NA	0	0	0
NE6	6	1	NA	0	0	0
NC11	7	1	NA	0	0	0
NC7	8	0	NA	0	0	0
NC3	9	1	NA	0	0	0
NC8	10	0	NA	0	0	0
NC10	11	1	NA	0	0	0
NC9	12	0	NA	0	0	0
NE5	13	0	NA	0	0	0
C2	14	0	NA	0	0	0
NC2	15	0	NA	0	0	0
C6	16	0	NA	0	0	0
C8	17	1	NA	0	0	0
C7	18	1	NA	0	0	0
C3	19	1	NA	0	0	0
NE1	20	0	NA	0	0	0
NE4	21	0	NA	0	0	0

continued

Table A.11 continued

		No. of Class III Adult Salamanders				
		2-Line	Longtail	Red	Mud	Spring
NC1	1	7	NA	0	0	0
NE3	2	1	NA	0	0	0
NE2	3	0	NA	0	0	0
C5	4	0	NA	0	0	0
C9	5	1	NA	0	0	0
NE6	6	0	NA	0	0	0
NC11	7	0	NA	0	0	0
NC7	8	0	NA	0	0	0
NC3	9	0	NA	0	0	0
NC8	10	0	NA	0	0	0
NC10	11	1	NA	0	0	0
NC9	12	0	NA	0	0	0
NE5	13	0	NA	0	0	0
C2	14	0	NA	0	0	0
NC2	15	0	NA	0	0	0
C6	16	2	NA	0	0	0
C8	17	1	NA	0	0	0
C7	18	6	NA	0	0	0
C3	19	0	NA	0	0	0
NE1	20	0	NA	0	0	0
NE4	21	0	NA	0	0	0

		Total No. of Class III Salamanders					
		2-Line	Longtail	Red	Mud	Spring	**TOTAL**
NC1	1	16	NA	0	0	0	16
NE3	2	16	NA	5	0	0	21
NE2	3	26	NA	1	0	0	27
C5	4	7	NA	0	0	0	7
C9	5	37	NA	0	0	0	37
NE6	6	9	NA	1	0	0	10
NC11	7	3	NA	0	0	0	3
NC7	8	0	NA	0	0	0	0
NC3	9	1	NA	0	0	0	1
NC8	10	0	NA	0	0	0	0
NC10	11	5	NA	0	0	0	5
NC9	12	2	NA	0	0	0	2
NE5	13	9	NA	2	0	0	11
C2	14	2	NA	0	0	0	2
NC2	15	31	NA	0	0	0	31
C6	16	10	NA	1	0	0	11
C8	17	2	NA	0	0	0	2
C7	18	12	NA	0	0	0	12
C3	19	8	NA	0	0	0	8
NE1	20	6	NA	0	0	0	6
NE3	21	10	NA	0	0	0	10

continued

Table A.11 continued

		Class III Salamander Relative Density (per m^2)					
		2-Line	Longtail	Red	Mud	Spring	Relative Density
NC1	1	1.01	NA	0.00	0	0	1.01
NE3	2	0.10	NA	0.03	0	0	0.14
NE2	3	1.07	NA	0.04	0	0	1.12
C5	4	0.75	NA	0.00	0	0	0.75
C9	5	3.60	NA	0.00	0	0	3.60
NE6	6	0.19	NA	0.02	0	0	0.21
NC11	7	0.11	NA	0.00	0	0	0.11
NC7	8	0.00	NA	0.00	0	0	0.00
NC3	9	0.02	NA	0.00	0	0	0.02
NC8	10	0.00	NA	0.00	0	0	0.00
NC10	11	0.16	NA	0.00	0	0	0.16
NC9	12	0.07	NA	0.00	0	0	0.07
NE5	13	0.41	NA	0.09	0	0	0.50
C2	14	0.20	NA	0.00	0	0	0.20
NC2	15	0.79	NA	0.00	0	0	0.79
C6	16	0.08	NA	0.01	0	0	0.09
C8	17	0.09	NA	0.00	0	0	0.09
C7	18	0.48	NA	0.00	0	0	0.48
C3	19	0.33	NA	0.00	0	0	0.33
NE1	20	1.00	NA	0.00	0	0	1.00
NE3	21	0.47	NA	0.00	0	0	0.47

Table A.11. Summary of salamander class III data for use in Salamander Community Quality Index development from reference and disturbed Primary Headwater Habitat sites in central, north-central, and northeast Ohio sampled during spring to fall 2004-05.

Site Name	Site No.	Class II Salamanders Present No. Dusky	Mtn. Dusky	Longtail
NC1	1	1	0	1
NE3	2	0	0	1
NE2	3	1	1	1
C5	4	0	0	0
C9	5	1	0	1
NE6	6	1	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	1	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	1	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

Site Name	Site No.	Class II Larval Salamanders Present No. Dusky	Mtn. Dusky	Longtail
NC1	1	1	0	1
NE3	2	0	0	0
NE2	3	0	0	0
C5	4	0	0	0
C9	5	1	0	0
NE6	6	1	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	0	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	0	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

continued

Table A.12 continued

Site Name	Site No.	Class II Juvenile/Adult Salamanders Present		
		No. Dusky	Mtn. Dusky	Longtail
NC1	1	1	0	1
NE3	2	0	0	1
NE2	3	1	1	0
C5	4	0	0	0
C9	5	0	0	0
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	1	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	1	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

Site Name	Site No.	Class II Juvenile Salamanders Present		
		No. Dusky	Mtn. Dusky	Longtail
NC1	1	1	0	0
NE3	2	0	0	0
NE2	3	0	0	1
C5	4	0	0	0
C9	5	1	0	0
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	0	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	0	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

continued

Table A.12 continued

Site Name	Site No.	Class II Adult Salamanders Present No. Dusky	Mtn. Dusky	Longtail
NC1	1	1	0	0
NE3	2	0	0	0
NE2	3	0	0	0
C5	4	0	0	0
C9	5	0	0	1
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	0	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	0	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

Site Name	Site No.	No. of Class II Juvenile/Adult Salamanders Present No. Dusky	Mtn. Dusky	Longtail
NC1	1	0	0	0
NE3	2	0	0	1
NE2	3	1	1	0
C5	4	0	0	0
C9	5	0	0	0
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	1	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	2	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

continued

Table A.12 continued

Site Name	Site No.	No. of Class II Juvenile Salamanders Present		
		No. Dusky	Mtn. Dusky	Longtail
NC1	1	2	0	0
NE3	2	0	0	0
NE2	3	0	0	1
C5	4	0	0	0
C9	5	2	0	0
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	0	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	0	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

Site Name	Site No.	No. of Class II Adult Salamanders Present		
		No. Dusky	Mtn. Dusky	Longtail
NC1	1	2	0	0
NE3	2	0	0	0
NE2	3	0	0	0
C5	4	0	0	0
C9	5	0	0	1
NE6	6	0	0	0
NC11	7	0	0	0
NC7	8	0	0	0
NC3	9	0	0	0
NC8	10	0	0	0
NC10	11	0	0	0
NC9	12	0	0	0
NE5	13	0	0	0
C2	14	0	0	0
NC2	15	0	0	0
C6	16	0	0	0
C8	17	0	0	0
C7	18	0	0	0
C3	19	0	0	0
NE1	20	0	0	0
NE4	21	0	0	0

continued

Table A.12 continued

Site Name	Site No.	Total No. of Class II Salamanders No. Dusky	Mtn. Dusky	Longtail	**TOTAL**
NC1	1	6	0	2	8
NE3	2	0	0	1	1
NE2	3	1	1	1	3
C5	4	0	0	0	0
C9	5	3	0	1	4
NE6	6	3	0	0	3
NC11	7	0	0	0	0
NC7	8	0	0	0	0
NC3	9	0	0	0	0
NC8	10	0	0	0	0
NC10	11	0	0	0	0
NC9	12	0	0	0	0
NE5	13	0	1	0	1
C2	14	0	0	0	0
NC2	15	0	0	0	0
C6	16	2	0	0	2
C8	17	0	0	0	0
C7	18	0	0	0	0
C3	19	0	0	0	0
NE1	20	0	0	0	0
NE4	21	0	0	0	0

Site Name	Site No.	Class II Salamander Relative Density (per m^2) No. Dusky	Mtn. Dusky	Longtail	**TOTAL**
NC1	1	0.61	0.00	0.20	0.81
NE3	2	0.00	0.00	0.01	0.01
NE2	3	0.04	0.04	0.04	0.12
C5	4	0.00	0.00	0.00	0.00
C9	5	0.29	0.00	0.10	0.39
NE6	6	0.06	0.00	0.00	0.06
NC11	7	0.00	0.00	0.00	0.00
NC7	8	0.00	0.00	0.00	0.00
NC3	9	0.00	0.00	0.00	0.00
NC8	10	0.00	0.00	0.00	0.00
NC10	11	0.00	0.00	0.00	0.00
NC9	12	0.00	0.00	0.00	0.00
NE5	13	0.00	0.05	0.00	0.05
C2	14	0.00	0.00	0.00	0.00
NC2	15	0.00	0.00	0.00	0.00
C6	16	0.03	0.00	0.00	0.03
C8	17	0.00	0.00	0.00	0.00

continued

Table A.12 continued

Site Name	Site No.	Class II Salamander Relative Density (per m^2)			
		No. Dusky	Mtn. Dusky	Longtail	**TOTAL**
C7	18	0.00	0.00	0.00	0.00
C3	19	0.00	0.00	0.00	0.00
NE1	20	0.00	0.00	0.00	0.00
NE4	21	0.00	0.00	0.00	0.00

Table A.12. Summary of salamander class II data for use in Salamander Community Quality Index development from reference and disturbed Primary Headwater Habitat sites in central, north-central, and northeast Ohio sampled during spring to fall 2004-05.

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count 1		2		3		4		5		6		7	
01320	*Hydra sp*	F		PR				7		1		2		73				
01801	Turbellaria	F		GC	+							4					+	10
01900	Nemertea	F		PR								3				1		16
02000	Nematoda	T		PA														8
02600	Nematomorpha	F						32		2		20		33		12		
03040	*Fredericella sp*	MI		FC						4			+					
03600	Oligochaeta	T		GC			+									2		
03700	Naididae	T		GC	+	3				167		82		101		21		73
03770	*Nais sp*	T		GC				468										
03900	Tubificidae	T		GC		1		81		75		63			+	21		60
04100	Lumbriculidae	T		GC		14		2		6		3		3		3		
04410	*Eiseniella tetraedra*	T		GC				1	+	36					+	3		4
07701	Cambaridae			GC								1						
07800	*Cambarus sp*	F		GC		2	+											
07820	*Cambarus (C.)sp A*	F		GC			+											
07860	*Cambarus (Puncti-cambarus)robustus*	F		GC					+				+		+	1		
08601	Hydrachnidia	F		PR		5		50	+	30	+	22		9		5	+	8
11010	*Acentrella sp*	I		GC		4												
11014	*Acentrella turbida*	I		GC			5											
11115	*Baetis tricaudatus*	MI	X	GC	+	261	+	17	+	188			+	73	+	253		
11120	*Baetis flavistriga*	F		GC	+	7								3				
11121	*Pseudocloeon sp*	I		GC								1						
11150	*Pseudocloeon propinquum*	I		GC								1						
11245	*Centroptilum sp*	MI		GC										1				
11400	*Centroptilum* or *Procloeon sp*	MI		GC						1								
11430	*Diphetor hageni*	I		GC	+	43	+			23	+	208	+	44	+	64		24
11590	*Paracloeodes sp*	I		GC		3												
11645	*Procloeon sp*	MI		GC		1												
12800	*Epeorus sp*	MI	X	SC	+	8												
13000	*Leucrocuta sp*	I		SC		1							+	54				
13100	*Nixe sp*	I		SC									+	21				
13400	*Stenacron sp*	F		GC	+	1	+								+			
13500	*Maccaffertium sp*	MI		SC		1									+			
13521	*Stenonema femoratum*	F		SC									+				+	24
13590	*Maccaffertium vicarium*	MI		SC	+	1					+		+	2			+	80
14501	Leptophlebiidae	MI		GC												2		
14700	*Habrophlebiodes sp*	MI	X	GC	+	1				8	+	12	+	297	+			
14900	*Leptophlebia sp*	I		GC							+	64	+					
15000	*Paraleptophlebia sp*	MI		GC	+	168		79	+	215	+	66	+	259	+	15		
15064	*Paraleptophlebia praepedita*	MI		GC			+			126								
15501	Ephemerellidae	MI		GC			+											
15600	*Ephemerella sp*	MI		GC	+	2												
16200	*Eurylophella sp*	MI		GC						14	+	42				20	+	281
16324	*Serratella deficiens*	I		GC	+													
17200	*Caenis sp*	F		GC								3		3				
21200	*Calopteryx sp*	F		PR		1					+		+				+	
21300	*Hetaerina sp*	F		PR														1

continued

Table A.13 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	Site Number Qual. = + / Quantitative Count 1		2		3		4		5		6		7	
22001	*Coenagrionidae*	MT		PR					+									
23600	*Aeshna sp*	F		PR							+							
23909	*Boyeria vinosa*	F		PR								1						
25210	*Lanthus parvulus*	MI	X	PR												1		
28001	Libellulidae	T		PR												1		
30000	Plecoptera									1								
32001	Nemouridae	MI		SH	+											1		
32200	*Amphinemura sp*	MI	X	SH	+	5						1	+	13	+	6		
33100	*Leuctra sp*	I	X	SH	+	783	+	20	+	134				568	+	58		
33501	Capniidae	MI		SH				3			+	679		206		340		
33600	*Allocapnia sp*	MT		SH	+													
33700	*Paracapnia sp*	MI		SH								15						
34001	Perlidae	MI		PR				2				1				6		
34100	*Acroneuria sp*	MI		PR	+	10								15				
34120	*Acroneuria carolinensis*	I		PR	+	5												
34130	*Acroneuria frisoni*	MI		PR									+	38				
34200	*Eccoptura xanthenes*	MI	X	PR									+					
35001	Perlodidae	MI		PR								1						
35500	*Isoperla sp*	MI		PR		14				10				6	+	7		
35540	*Isoperla namata*	MI		PR	+					2								
35560	*Isoperla similis*	I		PR	+		+											
36001	Chloroperlidae	MI		PR						9								
36200	*Haploperla brevis*	MI	X	PR		13		2							+	27		
36500	*Sweltsa sp*	MI	X	PR	+													
45300	*Sigara sp*	F		MP							+							
47600	*Sialis sp*	F		PR			+	6	+	21	+	8		15	+			
48600	*Nigronia sp*			PR			+							1				
48610	*Nigronia fasciatus*	MI	X	PR	+			1		2								
48620	*Nigronia serricornis*	F		PR	+													
50301	*Chimarra aterrima*	MI		FC							+	172		1			+	94
50315	*Chimarra obscura*	MI		FC								1						
50410	*Dolophilodes distinctus*	MI	X	FC	+	50			+	9						10		
50500	*Wormaldia sp*	MI	X	FC												4		
50804	*Lype diversa*	MI		SC												2		
51300	*Neureclipsis sp*	MI		FC		1												
51400	*Nyctiophylax sp*	MI		FC						1	+	1	+					
51600	*Polycentropus sp*	MI		FC	+	59		8	+	11			+	8		4		
52200	*Cheumatopsyche sp*	F		FC							+	116		5				
52315	*Diplectrona modesta*	F	X	FC	+	45	+	98	+	322	+	16	+	12	+	139		
52430	*Ceratopsyche morosa grp.*	MI		FC						2								
52440	*Ceratopsyche slossonae*	MI	X	FC	+	4	+			12		1						
52450	*Ceratopsyche sparna*	MI		FC						7								
52460	*Ceratopsyche ventura*	MI	X	FC			+			10						1		
52530	*Hydropsyche depravata grp.*	F		FC		1						8	+	4				
52701	*Parapsyche apicalis*	MI	X	FC				126		27					+	226		
53100	*Rhyacophila sp*	F	X	PR				3		36				1				
53101	*Rhyacophila minor*	I	X	PR												1		
53103	*Rhyacophila carolina*	MI	X	PR	+	7		3		16					+	31		
53104	*Rhyacophila fenestra or R. ledra*	F	X	PR				2										
53300	*Glossosoma sp*	MI	X	SC	+	12		4	+	21	+	25		2	+	13		
53400	*Protoptila sp*	I		SC											+			
53501	Hydroptilidae	F		SH								1	+					
53800	*Hydroptila sp*	F		SH										4				
56600	*Frenesia sp*	MI	X	SH				1										

continued

Table A.13 continued

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count													
						1		2		3		4		5		6		7
56650	*Goera stylata*	MI	X	SC					+	2		3						
56900	*Hydatophylax sp*	MI		SH							+					1		
57000	*Ironoquia sp*	F		SH		1												
57400	*Neophylax sp*	I		SC	+		+	5	+	32			+	2	+	2	+	
57900	*Pycnopsyche sp*	MI		SH	+	20		2	+		+	3			+	1		
58020	*Lepidostoma sp*	MI	X	SH		6	+	11	+	10						2		
58410	*Molanna sp*	MI	X	GC		1		15		2		1	+					
58505	*Helicopsyche borealis*	MI		SC							+							
59100	*Ceraclea sp*	MI		GC				2										
59300	*Mystacides sp*	MI		GC														12
59400	*Nectopsyche sp*	MI		SH						1								
59570	*Oecetis nocturna*	F		PR														4
59700	*Triaenodes sp*	MI		SH				3										
60900	*Peltodytes sp*	MT		SH							+							
61400	*Agabus sp*	MT		PR										10				
62300	*Coptotomus sp*	F		PR										124				
63300	Hydroporini	F		PR									+	5				
63900	*Laccophilus sp*	T		PR										1				
66200	*Cymbiodyta sp*	F		GC									+					
66901	*Helocombus bifidus*	F		GC						1								
67000	*Helophorus sp*	F		SH									+					
67100	*Hydrobius sp*	F		GC		1	+		+						+			
67700	*Paracymus sp*	F		GC									+					
68025	*Ectopria sp*	MI		SC			+	6	+	7	+	32		8			+	22
68075	*Psephenus herricki*	MI		SC									+	1				
68130	*Helichus sp*	MI		SC									+					
68601	*Ancyronyx variegata*	MI		GC				1										
68700	*Dubiraphia sp*	F		GC														217
69200	*Optioservus sp*	MI		SC				1	+									
69210	*Optioservus ampliatus*	MI		SC						9								
69225	*Optioservus fastiditus*	MI		SC								32						
69400	*Stenelmis sp*	F		SC		1				7		9	+	13			+	213
70000	*Diptera*													1				
70501	Tipulidae			GC				1						1				
70600	*Antocha sp*	MI		GC				6		40								
70700	*Dicranota sp*	MI	X	PR			+	3		3		5			+	33		
70800	*Erioptera sp*	MT		GC		1												
71100	*Hexatoma sp*	MI		PR	+	19	+	1				1	+	5	+	7		
71200	*Limnophila sp*	MI		PR								8				2		
71300	*Limonia sp*	F		SH				3								1		4
71500	*Ormosia sp*	F		GC		1												
71600	*Pedicia sp*	F	X	PR												1		
71700	*Pilaria sp*	F		PR												2		
71800	*Pseudolimnophila sp*	MI		GC		8						11		12				
71900	*Tipula sp*	F		SH		1								5		2		
71910	*Tipula abdominalis*	MI		SH	+	4	+				+	4	+				+	12
72340	*Dixella sp*	F		GC							+				+	4		
74100	*Simulium sp*	F		FC	+	3	+	96	+	44				8	+	134		
74501	Ceratopogonidae	F		PR		5	+	103		45		94		22		25	+	104
74650	*Atrichopogon sp*	F		GC								1				6		
74673	*Atrichopogon websteri*	F		GC														8
77280	*Brundiniella eumorpha*		X	PR												19		
77500	*Conchapelopia sp*	F		PR	+	309				4		150	+	84				430
77750	*Hayesomyia senata or Thienemannimyia norena*	F		PR		1		1		1		10		15		4		90
77800	*Helopelopia sp*	F		PR		19				7		49						49

continued

Table A.13 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	Site Number Qual. = + / Quantitative Count	1		2		3		4		5		6	7
78000	*Krenopelopia sp*			PR		1		19								1	
78200	*Larsia sp*	F		PR										55		3	
78300	*Macropelopia sp*		X	PR			+	1									
78350	*Meropelopia sp*	F	X	PR		2		9		1		2	+				
78402	*Natarsia baltimoreus*	F		PR		24	+	7		13		63		70		1	
78450	*Nilotanypus fimbriatus*	MI		PR		37		2		31		1		1		23	
78500	*Paramerina fragilis*	F		PR						2							
78510	*Paramerina sp 1*	MI		PR		1											
78600	*Pentaneura inconspicua*	F		PR						2							
78601	*Pentaneura Type 1*	F		PR										101			
78655	*Procladius (Holotanypus) sp*	MT		PR			+										
78750	*Rheopelopia paramaculipennis*	MI		PR		3											
79085	*Telopelopia okoboji*	F		PR										5			
79300	*Trissopelopia ogemawi*	MI	X	PR	+	13	+	109	+	32		5	+	19		4	
79400	*Zavrelimyia sp*	F	X	PR		27	+	62	+	35		48	+	996		7	37
79720	*Diamesa sp*	F	X	GC		2	+	88		1				7		3	
79761	*Pagastia orthogonia*	MI	X	GC	+	14	+	611	+	42					+	19	
79864	*Odontomesa ferringtoni*	F	X	GC		4											
79880	*Prodiamesa olivacea*	F	X	GC			+	5		1						8	
80204	*Brillia flavifrons group*	F		SH						4						3	
80210	*Brillia parva*		X	SH				2									
80330	*Chaetocladius piger*	F	X	GC	+	43		4			+	21		49			
80350	*Corynoneura sp*	MI		GC													
80351	*Corynoneura n.sp 1*	MI		GC		13		4		8		21		3		3	
80355	*Corynoneura sp 5*	MI	X	GC										1		7	
80360	*Corynoneura"celeripes" (Simpson & Bode, 1980)*	I		GC		1								18			
80370	*Corynoneura lobata*	MI		GC		4		55		9	+	53		305		22	8
80410	*Cricotopus (C.) sp*	F		SH		5								4			
80420	*Cricotopus (C.) bicinctus*	MT		SH										119			
80430	*Cricotopus (C.) tremulus group*	F		SH										13			
80550	*Diplocladius cultriger*	F		GC				1		6		82		74		7	
80830	*Heleniella sp*	I	X	GC		3						1					
80845	*Heterotrissocladius sp*	MI		GC													
80850	*Heterotrissocladius marcidus*	MI	X	GC		27	+	101	+	29		11		12		23	
80870	*Hydrobaenus sp*	T		GC				2						2			
80900	*Krenosmittia sp*	MI		GC	+	12								11		1	
81040	*Limnophyes sp*	MT		GC										9		9	
81200	*Nanocladius sp*			GC								6					
81270	*Nanocladius (N.) spiniplenus*	MI		GC										5			
81460	*Orthocladius (O.) sp*	F		GC		1						3		4			
81530	*Orthocladius lignicola*	F		SH		2		1		1				2			
81600	*Parachaetocladius sp*	MI	X	GC						61						8	29
81630	*Parakiefferiella sp*	F		GC		1								1			
81631	*Parakiefferiella n.sp 1*	F		GC		1											
81632	*Parakiefferiella n.sp 2*	MI		GC		38		10		3		2					
81633	*Parakiefferiella n.sp 5*	MI		GC		7											
81650	*Parametriocnemus sp*	MI	X	GC	+	84	+	201		48		79	+	966	+	612	
81690	*Paratrichocladius sp*	MI		GC										78			

continued

Table A.13 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	Site Number Qual. = + / Quantitative Count 1	2	3	4	5	6	7
81750	*Pseudorthocladius sp*			GC						4	
81800	*Psilometriocnemus triannulatus*	I	X	GC						129	
81810	*Rheocricotopus sp*			GC			2				
81811	*Rheocricotopus (R.) eminellobus*	MI	X	GC						+ 21	
81825	*Rheocricotopus (Psilo-cricotopus) robacki*	MI		GC		2					
81870	*Rheosmittia sp*	F		GC						219	
82070	*Synorthocladius semivirens*	I		GC	77		5				
82101	*Thienemanniella taurocapita*	I		GC				2	4		
82102	*Thienemanniella boltoni*	MI	X	GC			102	29	1	5	
82121	*Thienemanniella lobapodema*	MI		GC					10		
82141	*Thienemanniella xena*	F		GC	15			10	50	13	
82200	*Tvetenia bavarica grp.*	MI		GC	2	+ 24	89	47	100	+ 164	
82710	*Chironomus (C.) sp*	T		GC					1		
82730	*Chironomus (C.) decorus grp.*	T		GC							+
82800	*Cladopelma sp*	F		GC					+		
82820	*Cryptochironomus sp*	F		PR	2	+ 6	4	4	1	1	
83003	*Dicrotendipes fumidus*	F		GC				3			
83040	*Dicrotendipes neomodestus*	F		GC				5	2		12
83400	*Harnischia sp*	F		GC		1					
83820	*Microtendipes "caelum" (Simpson & Bode, 1980)*	MI		GC			1				
83840	*Microtendipes pedellus grp.*	MI		GC	+		+ 545	14	+ 358		151
83900	*Nilothauma sp*	MI				1					
84116	*Paracladopelma nereis*	I		GC			1		7	10	
84118	*Paracladopelma undine*	MI		GC	5	1	4		9	3	
84155	*Paralauterborniella nigrohalteralis*	F		GC		4	6			4	
84210	*Paratendipes albimanus or P. duplicatus*	MI		GC	+ 52	25	+ 12	13	+ 15	11	
84300	*Phaenopsectra obediens grp.*	F		GC					15		
84315	*Phaenopsectra flavipes*	F		GC			5	+ 10			
84430	*Polypedilum (P.) albicorne*	MI	X	GC	+ 29	+ 3	12	+ 13	+ 100	5	+
84440	*Polypedilum (Uresipedilum) aviceps*	MI	X	GC	+ 57	2	9	+ 22	+ 61	2	37
84450	*Polypedilum (Uresipedilum) flavum*	F		GC	1			27	4		
84470	*Polypedilum (P.) illinoense*	T		GC			1				
84480	*Polypedilum (P.) laetum group*	MI		GC	2	6	+ 3		2		
84540	*Polypedilum (Tripodura) scalaenum group*	F		GC		105	120	2	24	13	
84750	*Stictochironomus sp*	F		GC			+ 12	2	+ 65		

continued

Table A.13 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	Site Number Qual. = + / Quantitative Count													
						1		2		3		4		5		6		7
84790	*Tribelos fuscicorne*	F		GC										2				
85201	*Cladotanytarsus sp grp. A*	MI		GC					+									
85261	*Cladotanytarsus vanderwulpi grp . 1*	I		GC										1				
85400	*Micropsectra sp*	F	X	GC	+	8	+	72		31		9		369	+	138		12
85500	*Paratanytarsus sp*	F		GC		1					+	61		30				
85501	*Paratanytarsus n.sp 1*	MI	X	GC	+	24	+	749		150	+	81	+	268		7		117
85615	*Rheotanytarsus pellucidus*	MI		FC		2		17		2		12		10				12
85625	*Rheotanytarsus sp*	MI		FC		25	+	667		93		13	+	28		13		12
85702	*Stempellina sp 2*	MI		GC								3		1				
85711	*Stempellinella l eptocelloides*	I		GC						45		26		1		6		
85715	*Stempellinella boltoni*	I	X	GC		172				2		7						
85720	*Stempellinella fimbriata*	I		GC		22						6		68				
85752	*Sublettea coffmani*	I		GC		1												
85800	*Tanytarsus sp*	MI		GC		3		33		12		7		328				
85802	*Tanytarsus curticornis*	MI		GC		38		1	+	3		33				4		
85818	*Tanytarsus glabrescens grp. 4*	MI		GC					+									
85840	*Tanytarsus sepp*	MI		GC		1		133		26		44				7		49
85921	*Zavrelia aristata*	MI	X	GC								6				4		
85994	*Glutops sp*			PR												1		
86001	*Tabanidae*	F		PR						1								
86100	*Chrysops sp*	F		GC		1				10		51				3		
86200	*Tabanus sp*	F		PR		1						6	+					
86700	*Caloparyphus sp*	F		GC								1						
87510	*Neoplasta sp*	MI	X	PR		25		20		30		5				11		
87515	*Clinocera (C.) sp*	MI	X	PR						2				6		1		
87540	*Hemerodromia sp*	F		PR				5		2		1	+	1		1		8
89700	*Limnophora sp*	F		PR								2						
93900	*Elimia sp*	MI		SC							+	1						
94000	*Leptoxis sp*			SC								1						
94400	*Fossaria sp*	F		SC				3										
95100	*Physella sp*	T		SC			+	4	+	9	+	5		7				18
98200	*Pisidium sp*	F		FC						83		3				189		
98600	*Sphaerium sp*	F		FC				270		4		5		2		83		4

Table A.13. Qualitative (presence/absence data) and quantitative count data for invertebrates collected at Primary Headwater Habitat sample site numbers 1-7 sampled in central, north-central, and northeast Ohio from spring to fall 2004-05. Abbreviations: Tol.= tolerant; cat.=category; CW= coldwater; qual.= qualitative; tr. grp.= trophic group; sp species; grp.= group.

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count 8		9		10		11		12		13		14	
01320	*Hydra sp*	F		PR				8		24								
01801	Turbellaria	F		GC		1		1	+	48		14	+	85				11
01900	Nemertea	F		PR		5		68		20				48				
02000	Nematoda	T		PA		56		184		86		14		5				
02600	Nematomorpha	F						6				18		6				
03360	*Plumatella sp*	F		FC			+			2			+					1
03600	Oligochaeta	T		GC					+									
03650	Tubificida	T		GC			+	7037	+	1848								
03700	Naididae	T		GC				3		225		6		8	+	4		86
03900	Tubificidae	T		GC	+	3240						89		194			+	738
03925	*Branchiura sowerbyi*	T		GC										24				
04120	*Lumbriculus variegatus*	T		GC		3												1
04410	*Eiseniella tetraedra*			GC				3		1		11		32		1		
04664	*Helobdella stagnalis*	T		PR	+	189		29		1								
04935	*Erpobdella punctata punctata*	T		PR						1								
04964	*Mooreobdella microstoma*	T		PR		3		1										
06001	Amphipoda	F						2										
06700	*Crangonyx sp*	MT		GC										8				
07820	*Cambarus (C.)sp A*	F		GC					+		+			1				
07860	*Cambarus (Puncti-cambarus) robustus*	F		GC											+	3		
07880	*Cambarus (Tubericambarus) thomai*	T		GC	+													
08601	Hydrachnidia	F		PR						8				10				
11120	*Baetis flavistriga*	F		GC									+					
11200	*Callibaetis sp*	MT		GC					+	2								
11430	*Diphetor hageni*	I		GC										4			+	310
11650	*Procloeon sp (w/ hindwing pads)*	MI		GC												2		
13000	*Leucrocuta sp*	I		SC										1				
13400	*Stenacron sp*	F		GC					+						+	13		
13521	*Stenonema femoratum*	F		SC								5	+					
13561	*Maccaffertium pulchellum*	MI		SC													+	
13590	*Maccaffertium vicarium*	MI		SC							+	8	+	16			+	13
14700	*Habrophlebiodes sp*	MI	X	GC												13	+	160
14900	*Leptophlebia sp*	I		GC													+	
15000	*Paraleptophlebia sp*	MI		GC											+	106	+	96

continued

Table A.14 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	8	9	10	11	12	13	14
					Site Number Qual. = + / Quantitative Count						
16200	*Eurylophella sp*	MI		GC				83	1	+ 75	
17200	*Caenis sp*	F		GC		1	6				
18600	*Ephemera sp*	MI		GC						2	
21200	*Calopteryx sp*	F		PR				4	+		+
21300	*Hetaerina sp*	F		PR					+ 1	1	
22001	*Coenagrionidae*	MT		PR	+		+ 51				
22300	*Argia sp*	F		PR			+ 25				
23905	*Boyeria grafiana*	MI	X	PR							+
23909	*Boyeria vinosa*	F		PR						+ 1	
28955	*Plathemis lydia*	T		PR			+ 3				
33100	*Leuctra sp*	I	X	SH						+ 33	11
33501	Capniidae			SH		5			308	19	53
34130	*Acroneuria frisoni*	MI		PR						6	
34200	*Eccoptura xanthenes*	MI	X	PR						+ 2	
35500	*Isoperla sp*	MI		PR				9		16	
36200	*Haploperla brevis*	MI	X	PR						10	
47600	*Sialis sp*	F		PR						+ 7	+ 2
48610	*Nigronia fasciatus*	MI	X	PR						+ 4	
50301	*Chimarra aterrima*	MI		FC				+	+ 109		+ 481
50410	*Dolophilodes distinctus*	MI	X	FC					6	+ 5	19
50500	*Wormaldia sp*	MI	X	FC						+	
51400	*Nyctiophylax sp*	MI		FC							+
51600	*Polycentropus sp*	MI		FC						+	
52200	*Cheumatopsyche sp*	F		FC		1	+ 2	+ 20	+ 25		+ 224
52315	*Diplectrona modesta*	F	X	FC						+ 113	+ 25
52440	*Ceratopsyche slossonae*	MI	X	FC							16
52530	*Hydropsyche depravata group*	F		FC				+	10		+ 20
53100	*Rhyacophila sp*	F	X	PR						4	
53300	*Glossosoma sp*	MI	X	SC							+ 61
53800	*Hydroptila sp*	F		SH			2				
56650	*Goera stylata*	MI	X	SC						2	
57400	*Neophylax sp*	I		SC				+	+		
57900	*Pycnopsyche sp*	MI		SH							+ 3
58020	*Lepidostoma sp*	MI	X	SH						1	
58410	*Molanna sp*	MI	X	GC						11	
58505	*Helicopsyche borealis*	MI		SC					+		+
59930	*Crambus sp*				40						
60800	*Haliplus sp*	MT		SH	1						
60900	*Peltodytes sp*	MT		SH			+				
65800	*Berosus sp*	MT		SH			1				
67000	*Helophorus sp*	F		SH	+						

continued

Table A.14 continued

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	8	9	10	11	12	13	14
					Site Number Qual. = + / Quantitative Count						
67100	*Hydrobius sp*	F		GC							+
68025	*Ectopria sp*	MI		SC				+ 25		+ 27	13
68075	*Psephenus herricki*	MI		SC					+		
68601	*Ancyronyx variegata*	MI		GC							43
68700	*Dubiraphia sp*	F		GC		18			4		
68702	*Dubiraphia bivittata*	F		GC			20				
68901	*Macronychus glabratus*	MI		GC							32
69225	*Optioservus fastiditus*	MI		SC							+ 126
69400	*Stenelmis sp*	F		SC			5		+ 134		+ 63
70700	*Dicranota sp*	MI	X	PR						1	1
70800	*Erioptera sp*	MT		GC	6						
71000	*Helius sp*			GC	5						
71100	*Hexatoma sp*	MI		PR						+ 7	17
71200	*Limnophila sp*	MI		PR						2	
71500	*Ormosia sp*	F		GC	5						
71700	*Pilaria sp*	F		PR						5	
71800	*Pseudolimnophila sp*	MI		GC				4		1	
71900	*Tipula sp*	F		SH	2	+ 24			1		
71910	*Tipula abdominalis*	MI		SH		1		5		+	4
72340	*Dixella sp*	F		GC						10	+
74100	*Simulium sp*	F		FC			8		+ 4		
74501	Ceratopogonidae	F		PR	8	174	8	116	1	+ 47	48
74650	*Atrichopogon sp*	F		GC		1					
74673	*Atrichopogon websteri*	F		GC	2						
77120	*Ablabesmyia mallochi*	F		PR						1	32
77500	*Conchapelopia sp*	F		PR	18		4	+ 54	4	3	+ 75
77750	*Hayesomyia senata or Thienemannimyia norena*	F		PR	21			+ 141	14	2	43
77800	*Helopelopia sp*	F		PR				11	3		
78200	*Larsia sp*	F		PR						3	
78300	*Macropelopia sp*		X	PR							
78350	*Meropelopia sp*	F	X	PR	6			2	1		
78401	*Natarsia species A (Roback, 1978)*	T		PR		10		6			
78402	*Natarsia baltimoreus*	F		PR						1	
78450	*Nilotanypus fimbriatus*	MI		PR					1		
78655	*Procladius (Holotanypus) sp*	MT		PR		1		3			
79400	*Zavrelimyia sp*	F	X	PR		2		11		7	
80351	*Corynoneura n.sp 1*	MI		GC							+
80355	*Corynoneura sp 5*		X	GC				6			
80370	*Corynoneura lobata*	MI		GC						2	+

continued

Table A.14 continued

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count 8	9	10	11	12	13	14
80410	*Cricotopus (C.) sp*	F		SH					1		
80420	*Cricotopus (C.) bicinctus*	MT		SH	1		+ 25				
80430	*Cricotopus (C.) tremulus group*	F		SH			9	2			
80550	*Diplocladius cultriger*	F		GC		1					+
80845	*Heterotrissocladius sp*	MI		GC	1						
80850	*Heterotrissocladius marcidus*	MI	X	GC						2	
80870	*Hydrobaenus sp*	T		GC		7			10		
81040	*Limnophyes sp*	MT		GC	36					1	
81231	*Nanocladius (N.) crassicornus/"rectinervis"*	F		GC			2				11
81400	*Orthocladius sp*			GC					3		
81471	*Orthocladius (O.) oliveri*	MT		GC	4						
81630	*Parakiefferiella sp*	F		GC		2					
81650	*Parametriocnemus sp*	MI	X	GC						+ 18	+ 106
81690	*Paratrichocladius sp*	MI		GC				2			
81812	*Rheocricotopus (R.) effusoides*	MT		GC	3						
81890	*Smittia sp*			GC	3						
82100	*Thienemanniella sp*	F		GC					2		
82101	*Thienemanniella taurocapita*	I		GC							+ 43
82102	*Thienemanniella boltoni*	MI	X	GC							11
82141	*Thienemanniella xena*	F		GC			3				43
82200	*Tvetenia bavarica group*	MI		GC				3		1	53
82820	*Cryptochironomus sp*	F		PR				14		1	11
83840	*Microtendipes pedellus group*	MI		GC				113		+ 133	+ 32
84000	*Parachironomus sp*	F		GC				2			
84118	*Paracladopelma undine*	MI		GC				17			
84210	*Paratendipes albimanus or P. duplicatus*	MI		GC	4		1	24	1	2	629
84315	*Phaenopsectra flavipes*	F		GC			1				11
84430	*Polypedilum (P.) albicorne*	MI	X	GC				+ 3		1	+ 22
84440	*Polypedilum (Uresipedilum) aviceps*	MI	X	GC				+		3	+ 107
84450	*Polypedilum (Uresipedilum) flavum*	F		GC				+	+ 1		+ 138
84460	*Polypedilum (P.) fallax group*	F		GC							+ 64
84470	*Polypedilum (P.) illinoense*	T		GC			1				

continued

Table A.14 continued

Taxa Code	*Taxa Name*	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count													
						8		9		10		11		12		13		14
84480	*Polypedilum (P.) laetum group*	MI		GC													+	
84540	*Polypedilum (Tripodura) scalaenum group*	F		GC							+					2		
84790	*Tribelos fuscicorne*	F		GC													+	11
85400	*Micropsectra sp*	F	X	GC		19		17			+			1		3	+	75
85500	*Paratanytarsus sp*	F		GC													+	
85501	*Paratanytarsus n.sp 1*	MI	X	GC								16						11
85615	*Rheotanytarsus pellucidus*	MI		FC							+	2		3				22
85625	*Rheotanytarsus sp*	MI		FC							+	3		1			+	
85711	*Stempellinella leptocelloides*	I		GC														11
85715	*Stempellinella boltoni*	I	X	GC												13		
85720	*Stempellinella fimbriata*	I		GC								11				3		
85752	*Sublettea coffmani*	I		GC								2						
85800	*Tanytarsus sp*	MI		GC														11
85802	*Tanytarsus curticornis*	MI		GC								6			+	2		11
85840	*Tanytarsus sepp*	MI		GC				1				24						
85905	*Neostempellina reissi*	MI	X	GC												3		
85921	*Zavrelia aristata*	MI	X	GC												2		32
86100	*Chrysops sp*	F		GC		8						4				3		17
86200	*Tabanus sp*	F		PR														1
87250	*Odontomyia (Odontomyiina) sp*	F		GC		17												
87501	Empididae	F		PR		1												
87510	*Neoplasta sp (was Chelifera)*	MI	X	PR												4		11
87515	*Clinocera (C.) sp*	MI	X	PR												4		
87540	*Hemerodromia sp*	F		PR								2		1				11
89501	Ephydridae	F		GC		3												
93900	*Elimia sp*	MI		SC									+				+	6
94400	*Fossaria sp*	F		SC		6		1										21
95100	*Physella sp*	T		SC	+	10	+	116	+	48	+	48	+					1
95907	*Gyraulus (Torquis) parvus*	MT		SC						3								
96120	*Menetus (Micromenetus) dilatatus*	T		SC		1			+	20								

continued

Table A.14 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	Site Number Qual. = + / Quantitative Count 8	9	10	11	12	13	14
96200	*Planorbella sp*	T		SC	+ 30						
96264	*Planorbella (Pierosoma) pilsbryi*	T		SC			+ 50				
96900	*Ferrissia sp*	F		SC					2		
98200	*Pisidium sp*	F		FC	44	114	8	72	4	+ 4	+ 16
98600	*Sphaerium sp*	F		FC	2	35	+ 41				16

Table A.14. Qualitative (presence/absence data) and quantitative count data for invertebrates collected at Primary Headwater Habitat sample site numbers 8-14 sampled in central, north-central, and northeast Ohio from spring to fall 2004-05. Abbreviations: Tol.= tolerant; cat.=category; CW= coldwater; qual.= qualitative; tr. grp.= trophic group; sp species; grp.= group.

Taxa Code	*Taxa Name*	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count													
					15		16		17		18		19		20		21	
00401	Spongillidae	MI		FC				1										
01320	*Hydra sp*	F		PR						4								
01801	Turbellaria	F		GC			+	2	+	18			+	171	+	30		
01900	Nemertea	F		PR		1				24			+	39		5		
02000	Nematoda	T		PA				4		4						60		
02600	Nematomorpha	F														5		
03301	Plumatellidae			FC					+									
03360	*Plumatella sp*	F		FC							+							
03600	Oligochaeta	T		GC		9												2
03700	Naididae	T		GC				34		24		16		3		288		2
03770	*Nais sp*	T		GC										2				
03900	Tubificidae	T		GC				42	+	392		18			+	567		
03925	*Branchiura sowerbyi*	T		GC				10										
04410	*Eiseniella tetraedra*	T		GC	+	46		4		4	+	3		3	+	41		
04664	*Helobdella stagnalis*	T		PR						9								
04666	*Helobdella triserialis*	T		PA					+									
05800	*Caecidotea sp*	MT		SH					+	18								
05900	*Lirceus sp*	F		SH			+	318					+	697				1
06700	*Crangonyx sp*	MT		GC			+	1		5								
07840	*Cambarus (Cambarus) sciotensis*	F		GC			+	1		1	+	5						
07860	*Cambarus (Puncti-cambarus) robustus*	F		GC	+													
07875	*Cambarus (Tubericambarus) polychromatus*	MI		GC		2											+	1
08200	*Orconectes sp*	F		GC				1										
08601	Hydrachnidia	F		PR								20		2				3
10600	*Siphlonurus sp*	F		GC							+							
11115	*Baetis tricaudatus*	MI	X	GC		19												
11120	*Baetis flavistriga*	F		GC		1					+	20					+	3
11250	*Centroptilum sp (w/o hindwing pads)*	MI		GC	+	2					+							
11430	*Diphetor hageni*	I		GC		52												
13000	*Leucrocuta sp*	I		SC		3						69						
13100	*Nixe sp*	I		SC							+							
13521	*Stenonema femoratum*	F		SC			+	2										
13590	*Maccaffertium vicarium*	MI		SC				5										
14700	*Habrophlebiodes sp*	MI	X	GC		1						18						
15000	*Paraleptophlebia sp*	MI		GC	+	2		2	+	36	+	94						

continued

Table A.15 continued

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	Site Number Qual. = + / Quantitative Count 15		16		17		18		19		20		21	
16200	*Eurylophella sp*	MI		GC	+	84												
21200	*Calopteryx sp*	F		PR													+	
22001	*Coenagrionidae*	MT		PR					+									
25210	*Lanthus parvulus*	MI	X	PR		2												
32200	*Amphinemura sp*	MI	X	SH							+	18						
33100	*Leuctra sp*	I	X	SH	+	71		4				38						
33501	Capniidae			SH				2	+	8		17		7				1
34120	*Acroneuria carolinensis*	I		PR													+	
35150	*Clioperla clio*	MI		PR									+	5				
35250	*Diploperla robusta*	MI		PR							+	18						
35500	*Isoperla sp*	MI		PR				19										
36200	*Haploperla brevis*	MI	X	PR		59		2			+	12					+	12
36500	*Sweltsa sp*	MI	X	PR													+	40
47600	*Sialis sp*	F		PR	+	1	+	10			+	3	+	1				
48610	*Nigronia fasciatus*	MI	X	PR	+	6						1					+	
50301	*Chimarra aterrima*	MI		FC													+	1
50410	*Dolophilodes distinctus*	MI	X	FC								4					+	
50500	*Wormaldia sp*	MI	X	FC							+							
51600	*Polycentropus sp*	MI		FC		21			+		+				+			2
52200	*Cheumatopsyche sp*	F		FC		5	+								+	13	+	3
52315	*Diplectrona modesta*	F	X	FC	+	125	+	4			+	1	+	6	+		+	15
52440	*Ceratopsyche slossonae*	MI	X	FC													+	1
52530	*Hydropsyche depravata grp.*	F		FC			+										+	1
53100	*Rhyacophila sp*	F	X	PR		1			+									
53103	*Rhyacophila carolina*	MI	X	PR							+	1						
53800	*Hydroptila sp*	F		SH												28		
57400	*Neophylax sp*	I		SC	+	3					+		+					
57900	*Pycnopsyche sp*	MI		SH	+	8												
58020	*Lepidostoma sp*	MI	X	SH		1												
58410	*Molanna sp*	MI	X	GC		2												
61400	*Agabus sp*	MT		PR								8			+	6		
63300	Hydroporini	F		PR							+	1	+				+	
63700	*Ilybius sp*	T		PR											+	1		
66200	*Cymbiodyta sp*	F		GC	+													
68025	*Ectopria sp*	MI		SC			+	5	+	15		1	+	2				
68075	*Psephenus herricki*	MI		SC			+	2									+	
69400	*Stenelmis sp*	F		SC			+	62	+	454			+	30				2
70000	*Diptera*					5		1		2		4		1				
70700	*Dicranota sp*	MI	X	PR		3												
71100	*Hexatoma sp*	MI		PR	+	8						3					+	
71200	*Limnophila sp*	MI		PR		4												
71300	*Limonia sp*	F		SH												4		

continued

Table A.15 continued

Taxa Code	Taxa Name	Tol. Cat.	C W	Tr. Grp.	15 Qual.	15	16 Qual.	16	17 Qual.	17	18 Qual.	18	19 Qual.	19	20 Qual.	20	21 Qual.	21
					Site Number Qual. = + / Quantitative Count													
71500	*Ormosia sp*	F		GC												4		
71700	*Pilaria sp*	F		PR	+	7												
71800	*Pseudolimnophila sp*	MI		GC		1		6		1	+	32					+	
71900	*Tipula sp*	F		SH	+	5												
71910	*Tipula abdominalis*	MI		SH			+	13	+	6		1	+	4			+	1
74100	*Simulium sp*	F		FC											+	11		
74501	Ceratopogonidae	F		PR		227		4		4	+	52				8		4
74650	*Atrichopogon sp*	F		GC										2				
74673	*Atrichopogon websteri*	F		GC		2		2										
77001	Tanypodinae			PR												2		
77500	*Conchapelopia sp*	F		PR		122		6		1					+	2		3
77750	*Hayesomyia senata or Thienemannimyia norena*	F		PR		52		2		5		1			+	12		
77800	*Helopelopia sp*	F		PR		106										2		
78200	*Larsia sp*	F		PR						1	+	154						
78350	*Meropelopia sp*	F	X	PR				2						1	+			
78402	*Natarsia baltimoreus*	F		PR				9			+	29	+					7
78450	*Nilotanypus fimbriatus*	MI		PR								17						3
78599	*Pentaneura sp*	F		PR								3						
79300	*Trissopelopia ogemawi*	MI	X	PR	+	70												
79400	*Zavrelimyia sp*	F	X	PR	+	52		8		2	+	16		1	+	33		25
79720	*Diamesa sp*	F	X	GC											+	7	+	
79880	*Prodiamesa olivacea*	F	X	GC											+	2		
80330	*Chaetocladius piger*	F	X	GC				2							+	17		
80355	*Corynoneura sp 5*		X	GC										2				7
80370	*Corynoneura lobata*	MI		GC		18		2		2		37		7		285		1
80400	*Cricotopus sp*			SH						1								
80410	*Cricotopus (C.) sp*	F		SH												17		
80550	*Diplocladius cultriger*	F		GC						2		1						
80740	*Eukiefferiella claripennis grp.*	MT		GC												8		
80830	*Heleniella sp*	I	X	GC	+	176												
80850	*Heterotrissocladius marcidus*	MI	X	GC		18						3						
80870	*Hydrobaenus sp*	T		GC				3		9		2						
81231	*Nanocladius (N.) crassicornus/"rectinervis"*	F		GC						1								
81400	*Orthocladius sp*			GC				1										
81650	*Parametriocnemus sp*	MI	X	GC	+	298				2		29				4		2
81750	*Pseudorthocladius sp*			GC				1										
81800	*Psilometriocnemus triannulatus*	I	X	GC		18		1				3						
81810	*Rheocricotopus sp*			GC				1										
81890	*Smittia sp*			GC								3						

continued

Table A.15 continued

Taxa Code	Taxa Name	Tol. Cat.	CW	Tr. Grp.	15 Qual.	15 Quant.	16 Qual.	16 Quant.	17 Qual.	17 Quant.	18 Qual.	18 Quant.	19 Qual.	19 Quant.	20 Qual.	20 Quant.	21 Qual.	21 Quant.
					Site Number Qual. = + / Quantitative Count													
82141	*Thienemanniella xena*	F		GC								16						
82200	*Tvetenia bavarica group*	MI		GC				1										
82885	*Cryptotendipes pseudotener*	MI		GC		18												
83840	*Microtendipes pedellus grp.*	MI		GC				13		5		3						
84114	*Paracladopelma nais*	MI		GC												2		
84210	*Paratendipes albimanus or Paratendipes duplicatus*	MI		GC	+			10		22	+	51		1	+	137		
84315	*Phaenopsectra flavipes*	F		GC												8		
84430	*Polypedilum (P.) albicorne*	MI	X	GC		52		1		1	+	3			+			
84450	*Polypedilum (Uresipedilum) flavum*	F		GC														1
84470	*Polypedilum (P.) illinoense*	T		GC												10		
84475	*Polypedilum (P.) ophioides*	MI		GC												2		
84540	*Polypedilum (Tripodura) scalaenum group*	F		GC												2		
84750	*Stictochironomus sp*	F		GC				1										
85400	*Micropsectra sp*	F	X	GC		158				1						68		
85715	*Stempellinella boltoni*	I	X	GC		36												
85720	*Stempellinella fimbriata*	I		GC		18												
85800	*Tanytarsus sp*	MI		GC					+	1		3				2		
85802	*Tanytarsus curticornis*	MI		GC		122				1		10						
85840	*Tanytarsus sepp*	MI		GC	+					2								1
85910	*"Constempellina" n. sp 1*	MI	X	GC								8						
86100	*Chrysops sp*	F		GC		41		5										
87501	Empididae	F		PR									+					
87510	*Neoplasta sp (formerly Chelifera)*	MI	X	PR		2												
87601	Dolichopodidae	F		PR		8								2				1
95100	*Physella sp*	T		SC					+	8				4	+	42	+	
96002	*Helisoma anceps anceps*	MT		SC					+									
96264	*Planorbella (Pierosoma) pilsbryi*	T		SC					+									
98001	Sphaeriidae			FC												8		
98200	*Pisidium sp*	F		FC		16		1	+	191								
98600	*Sphaerium sp*	F		FC		7		4		28				2				

Table A.15. Qualitative (presence/absence data) and quantitative count data for invertebrates collected at Primary Headwater Habitat sample site numbers 15-21 sampled in central, north-central, and northeast Ohio from spring to fall 2004-05. Abbreviations: Tol.= tolerant; cat.=category; CW= coldwater; qual.= qualitative; tr. grp.= trophic group; sp species; grp.= group.

Primary Headwater Habitat Invertebrate Community Index (PHWH ICI)

Bug Metric	Metric Score Equation	Metric Score (0-1)	X 7 pts.	Final Metric Pts.
TNTXQTQL	y = 0.01205x		7	
NOQLTX	y = 0.03125x		7	
NMAYTXQQ	y = 0.14286x		7	
NSTNTXQQ	y = 0.2x		7	
NCADTXQQ	y = 0.09095x		7	
TNCWTXQQ	y = 0.05x		7	
NCWMITQQ	y = 0.1111x		7	
PCWTXOTC	y = 0.025x		7	
NSENTXQQ	y = 0.025x		7	
PSNTXOTC	y = 0.015385x		7	
PSENMYQT	y = 0.08x		7	
TCST2FAT	y = 0.55556x		7	
SSH2NSSH	If ratio x < 0.08 then score 0		7	
	If ratio x > 30 then score 1		7	
	y = 0.2991 + 0.27147 log x		-	
	Then y / 0.700 = metric score		7	
PTOLOTCT	If x $\leq$ 5.00% then score 1		7	
	If x $\geq$ 27.73% then score 0		7	
	y = -0.044 x + 1.22		7	
SubTotal			7	
X Constant				X 1.0204
FINAL PHWH ICI SCORE (OF 100%) =				

Table A.16. Primary Headwater Habitat Invertebrate Community Index scoring form developed for use in assessing primary headwater streams in Ohio.

Primary Headwater Habitat Invertebrate Community Index (PHWH ICI)

Bug Metric	Metric Score Equation		Metric Score (0-1)	X 7 pts.	Final Metric Pts.
TNTXQTQL	y = 0.01205x	x=83	**1.0**	7	**7.0**
NOQLTX	y = 0.03125x	x=39	**1.0**	7	**7.0**
NMAYTXQQ	y = 0.14286x	x=6	**0.86**	7	**6.02**
NSTNTXQQ	y = 0.2x	x=2	**0.40**	7	**2.80**
NCADTXQQ	y = 0.09095x	x=10	**0.91**	7	**6.37**
TNCWTXQQ	y = 0.05x	x=19	**0.95**	7	**6.65**
NCWMITQQ	y = 0.1111x	x=10	**1.0**	7	**7.0**
PCWTXOTC	y = 0.025x	x=16.49(%)	**0.412**	7	**2.884**
NSENTXQQ	y = 0.025x	x=48	**1.0**	7	**7.0**
PSNTXOTC	y = 0.015385x	x=57.0(%)	**0.877**	7	**6.14**
PSENMYQT	y = 0.08x	x=12.5(%)	**1.0**	7	**7.0**
TCST2FAT	y = 0.55556x	x=1.33	**0.739**	7	**5.173**
SSH2NSSH	If ratio x < 0.08 then score 0			7	
x= 71	If ratio x > 30 then score 1		**1.0**	7	**7.0**
	y = 0.2991 + 0.27147 log x			-	
	Then y / 0.700 = metric score			7	
PTOLOTCT	If x ≤ 5.00% then score 1			7	
	If x ≥ 27.73% then score 0			7	
x=17.8(%)	y = -0.044x + 1.22		**0.437**	7	**3.059**
SubTotal			11.585	7	81.096
X Constant					X 1.0204
FINAL PHWH ICI SCORE (OF 100%) =					**82.7**

Table A.17. Primary Headwater Habitat Invertebrate Community Index scoring form with site C2 (14) data from central Ohio in fall 2005 with scores shown as example guide for scoring primary headwater streams in Ohio