# Biological Evaluation of the Obion Creek Corridor Restoration Demonstration Project: Pre-restoration Monitoring Final Report

Kentucky Department for Environmental Protection
Division of Water
Watershed Management Branch
Nonpoint Source Section

2004

*Cover photograph descriptions, clockwise from top left*: Obion Creek above KY 339 (OBCR4); Debris accumulation in Obion Creek at KY 307; Obion Creek in the Obion Creek Wildlife Management Area (OBCR1); Construction of the restored Obion Creek channel.

*Suggested Citation*: McMurray, S.E. 2004. Biological evaluation of the Obion Creek corridor restoration demonstration project: pre-restoration monitoring final report. Kentucky Environmental and Public Protection Cabinet, Department for Environmental Protection, Division of Water, Frankfort.



Funding for this project was provided in part by a grant from the U.S. Environmental Protection Agency (USEPA) to the Kentucky Division of Water, Nonpoint Source Section, as authorized by the Clean Water Act Amendments of 1987, §319(h) Nonpoint Source Implementation Grant # C9994861-01-0. Mention of trade names or commercial products, if any, does not constitute endorsement. This document was printed on recycled paper.

# Biological Evaluation of the Obion Creek Corridor Restoration Demonstration Project: Pre-restoration Monitoring Final Report

By

Stephen E. McMurray, Environmental Biologist III

Kentucky Environmental and Public Protection Cabinet
Department for Environmental Protection
Division of Water
Watershed Management Branch
Nonpoint Source Section
14 Reilly Road
Frankfort, Kentucky 40601

This report has been approved for release:

____________________________
Jeffrey W. Pratt, Director
Division of Water

____________________________
Date

## Table of Contents

**Acknowledgments**

Former and present KDOW employees J. Brumley, D. Peake, R. Pierce, R. Payne, G. Pond, N. Powell and M. Vogel are graciously thanked for their assistance in the field and laboratory. In addition, R. Pierce and G. Pond are thanked for their assistance with data analysis and the writing of this report. A. Parola and W. Vesely, Univ. of Louisville, graciously provided the restoration design included in Figure 1. J. Ferguson, R. Pierce, G. Pond, M. Vogel (KDOW) and G. Schuster (Eastern Kentucky University) are thanked for their review and helpful comments, as are M. Chamberlain (KDOW) and K. Holt (EPPC). This work was funded, in part, by a grant from the U.S. Environmental Protection Agency (USEPA) to the Kentucky Division of Water, Nonpoint Source Section, as authorized by the Clean Water Act Amendments of 1987, §319(h) Nonpoint Source Implementation Grant # C9994861-01-0 (P.L. 100-4).

**List of Figures**

Figure

## List of Tables

Table

# Executive Summary

Nationally, over 146,450 km and in Kentucky 2,353 km of the assessed rivers and streams are affected by hydromodification (including channelization) and habitat modification. The perceived benefits of channelization (e.g., flood conveyance) are often offset by the ecological consequences of channelization (e.g., loss of habitat). Often, channelization has the result of increasing the problem that was originally to be addressed, such as flooding, rather than fix it. The objectives of this project were to determine the baseline water quality of a channelized section of Obion Creek prior to a proposed channel restoration project using macroinvertebrate assemblages, habitat and physicochemical parameters and to determine the limiting habitat parameters that would be addressed by restoration that could be used as restoration goals. The goal of this project is to determine success, in terms of the biota, of the restoration project in conjunction with post-restoration monitoring and to evaluate the effectiveness of stream channel restoration as an acceptable best management practice (BMP)/remediation practice to control nonpoint source (NPS) pollution in Kentucky. This evaluation is valuable to the evolving science of ecosystem restoration. Obion Creek is a second priority waterbody for Total Maximum Daily Load (TMDL) development due to nonsupport of aquatic life from sedimentation caused by streambank modification, destabilization and hydromodification, and a segment (mp 46.7–56.0) is recognized as a second priority nonpoint source impacted stream. The proposed restoration of approximately 1732 m of stream channel in two reaches is in a 2.0 km (1.25 mi) segment in the vicinity of KY 307.

Macroinvertebrates, habitat and physicochemical parameters (temperature, D.O., %saturation, pH and specific conductance) were sampled at four monitoring locations during the spring index period (May–June) from 2000–2003 with the Rapid Bioassessment Protocols (RBPs) for low-gradient streams. A one-way Analysis of Variance (ANOVA), Tukey's multiple-comparison procedure (*F*) and boxplots were used for between-site comparisons of the biological, habitat and physicochemical data. An unbiased version of Simpson's Index (*D*) and Morisita's Index of Similarity ($C_\lambda$) were used as measures of macroinvertebrate community diversity and community similarity, respectively. Relationships between genus-level macroinvertebrate, habitat and physicochemical values were elucidated using Pearson's correlation coefficient (*r*), a Canonical Correspondence Analysis (CCA) with rare species downweighted, and linear regression techniques. Habitat and physicochemical parameter values were correlated with CCA Axis 1 values to ascertain significant relationships. Data were $\log_{10\,(x+1)}$ or $\mathrm{Log}_{10}$ transformed for analyses; differences were considered significant at $\alpha \leq 0.1$.

There were no significant between-site differences in G-TotInd, MBI, catchment area, BankVegP and temperature, and substantial between-site differences (ANOVA, $0.1 < p \leq 0.2$) were observed in %CO, G-TR and PoolSubChar. Significant (ANOVA, $p \leq 0.1$) between-site differences were observed in m%EPT, %Cling, G-EPT, mHBI, AvgTolVal, BankSta, ChaFlowS, ChanAlter, ChanSin, EpiFauSub, PoolVar, RipVegZW, SedDep, TotHabSc, %saturation, D.O. and specific conductance. Significant correlations (i.e., $r \geq 0.300$, $p \leq 0.1$) were observed in 42 of the macroinvertebrate metric × habitat/physicochemical parameter combinations. The strongest correlations between *in situ* measured habitat parameters and a macroinvertebrate metric were PoolSubChar × mHBI ($r = -0.689$, p = 0.006), PoolVar × G-TotInd ($r = 0.623$, p =0.017), PoolVar × mHBI ($r = -0.613$, p 0.020), PoolSubChar × AvgTolVal ($r = -0.611$, p = 0.020) and ChanAlter × m%EPT ($r = -0.608$, p = 0.021).

The first 4 CCA environmental axes accounted for 53.3% of the variation observed in the macroinvertebrate communities. Axes 1 and 2 accounted for 31.3% of the variation, with Axis 1 accounting for the majority (16.5%); however, there was only a small difference between Axis 1 and Axis 4. Collection year ($r = 0.469$, p = 0.090), Catchment area ($r = -0.658$, p = 0.011) and the habitat parameters ChanSin ($r = 0.524$, p = 0.055), PoolSubChar ($r = -0.551$, p = 0.041) and PoolVar ($r = -0.463$, p = 0.095) were significantly correlated with CCA Axis 1. The physicochemical parameters %saturation ($r = -0.605$, p = 0.022), D.O. ($r = -0.611$, p = 0.020) and specific conductance ($r = 0.786$, p = 0.001) were also significantly correlated with the first CCA axis. The habitat parameters BankVegP ($r = 0.560$, p = 0.037), ChaFlowS ($r = 0.732$, p = 0.003), ChanAlter ($r = 0.615$, p = 0.019), ChanSin ($r = 0.544$, p =

0.044), EpiFauSub ($r$ = 0.574, p = 0.032), SedDep ($r$ = 0.635, p = 0.015) and TotHabSc ($r$ = 0.641, p = 0.014), as well as the physicochemical parameters %saturation ($r$ = -0.653, p = 0.011) and D.O. ($r$ = -0.665, p = 0.010), were significantly correlated with the second CCA Axis, which accounted for 14.8% of the variation in the macroinvertebrate communities.

Overall, all sites had Fair narrative water quality assessment ratings during each year of the project, with the exception of OBCR1 (2000), OBCR4 (2001, Good) and OBCR3 (2002). The lower values of m%EPT, %Cling, and G-EPT, and the higher mHBI and AvgTolVal values at OBCR2 were indicative of poorer water quality. Diversity and evenness values indicated highly diverse and evenly distributed macroinvertebrate communities at all sites over the course of the project. With the exception of OBCR2 during 2002 (Supporting, But Threatened), TotHabSc values for OBCR1 and OBCR2 corresponded to narrative assessment ratings of Fully Supporting designated uses. Habitat was found to be Supporting, But Threatened at OBCR4 during 2000 and 2001, Partially Supporting at OBCR4 during 2002, and Not Supporting at OBCR3 (all years) and OBCR4 during 2003. Overall, the similar TotHabSc values at OBCR1 and OBCR2 were indicative of higher quality habitat.

Regardless of the presence of vegetated riparian zones, historical land-use activities, especially large-scale agricultural activities, can have long-term detrimental effects on biotic communities. Since the goal of this study will be to determine improvements in macroinvertebrate community structure following restoration, improvements in water quality should not be used to determine success. Improvements in water quality, however, may in fact be realized through channel restoration.

Depending on water quality conditions and existence of nearby sources of colonizing organisms, improvements in ChanSin, EpiFauSub, PoolSubChar, PoolVar and SedDep should result in improvements in the macroinvertebrate fauna in the restored reaches. Given the direct relationships between these habitat features and macroinvertebrate community diversity, improvements in m%EPT, mHBI, G-TotInd, G-EPT, and AvgTolVal values should be observed following the restoration of Obion Creek. Because of the inherent natural variability in biological communities and the documented variability in habitat and macroinvertebrate community recovery rates, yearly post-restoration monitoring should be conducted for a minimum of four years to document improvements in the macroinvertebrate communities. It is also suggested that post-restoration monitoring be repeated following the initial sampling at some point in the future (i.e., every 2 years for 10 years) in order to document the long-term effects that restoration of Obion Creek may have on the macroinvertebrate communities.

## 1.0 Introduction

Nationally, more than 146,450 km (91,000 miles, approximately 13%) of assessed rivers and streams are affected by hydromodification (including channelization) and habitat modification (USEPA 2000). In Kentucky, large-scale human manipulation of water resources began with the completion of a canal and lock on the Ohio River near Louisville in 1830 (USACOE 1995), and hydromodification and habitat modification currently affect more than 2,353 km (1462 miles) of rivers and streams in the Commonwealth (KDOW 2004). Streams in lowland areas are usually the most altered because of the intensive use of these areas (Osborne et al. 1993). The perceived benefits of channelization (e.g., flood conveyance) are often offset by the ecological consequences of channelization (e.g., loss of habitat) (FISRWG 1998). These efforts often have the result of increasing the problem that was originally to be addressed by channelization, such as flooding, rather than fixing it (Rosgen 1996).

Channelization often leads to a myriad of problems including decreased baseflows, changes in physical habitat (e.g., bank erosion, sedimentation, decrease in substrate diversity), loss of riparian vegetation and changes in hydrology (e.g., power, roughness, sediment transport abilities) and channel dimensions (Brookes 1988). These changes in the physical structure and hydrology of lotic systems result in alterations of downstream energy dynamics and reduced or eliminated in-stream habitat (Gore et al. 1995, Davis et al. 2003). Channelized streams often re-adopt sinuosity within the constructed channel (e.g., Landwehr and Rhoads 2003). Channelization, by its nature, is accomplished with complete disregard of the biotic community, often altering the substrate to such a degree that it can never return to its original condition (Hynes 1974), such that natural biological recovery is nearly impossible (Gore et al. 1995). There are both direct and indirect effects of channelization on fish and aquatic macroinvertebrate communities, including loss of habitat and changes in food sources (Etnier 1972). Channelized streams have been found to have lower leaf litter retention rates and tend to be dominated by a few abundant taxa (Laasonen et al. 1998).

Aquatic organisms have been used to assess water quality impacts since the early 1900s (Cairns and Pratt 1993, Karr and Chu 1999). Since biological communities respond to a multitude of cumulative stressors over time, they represent an overall measure for determining water quality impairments (Angermeier 1997, USEPA 1997). Macroinvertebrates are an important component of the energy transport and utilization in lotic systems (Gore et al. 1995), and macroinvertebrate assemblages are useful in detecting even subtle water quality impairments (Barbour et al. 1999, KDOW 2002). Instream faunal improvements can be observed through the process of habitat restoration and increased colonization potential (Gore et al. 1995). While early habitat enhancement and stream restoration attempts, especially those completed with little knowledge of stream geomorphology, were either ineffective or outright failures (e.g., Ehlers 1956, Babcock 1986, Frissell and Nawa 1992, Kondolf 1995), restoration efforts that mimic the natural geomorphology of a reference stream will allow for improvements in water quality and biota (Osborne et al. 1993, Kondolf 1998) and have shown positive responses in macroinvertebrate communities (e.g., Friberg et al. 1994 and 1998, Gørtz 1998, Latimore 2000, Purcell et al. 2002).

The Obion Creek Watershed Conservancy District proposed to restore a channelized section of Obion Creek with the goal of restoring a naturalized flow and stream channel, thereby reducing sedimentation, bottomland hardwood wetland habitat loss and the flood hazard to KY 307 (KDOW 1999a). The objectives of this project are to determine the baseline water quality of Obion Creek in the project area using macroinvertebrate assemblages, habitat and physicochemical parameters prior to channel restoration and to determine the limiting habitat parameters that would be addressed by restoration that could be used as restoration goals. Ultimately, the goal of this project will be to determine success, in terms of the biota, of the restoration project in conjunction with post-restoration monitoring and to evaluate the effectiveness of stream channel restoration as an acceptable best management practice (BMP)/remediation practice to control nonpoint source (NPS) pollution in Kentucky. This evaluation is important to the evolving science of ecosystem restoration (Osborne et al. 1993, Friberg et al. 1994, Gore et al. 1995, Kondolf 1995 and 1998, Brookes 1990, Bash and Ryan 2002, Davis et al. 2003).

## 2.0 Materials and Methods

### *2.1 Study Area Description and Monitoring Station Selection*

Obion Creek is a low-gradient, spring-fed, $5^{th}$ order stream currently with few riffle areas that originates in southern Graves County, Kentucky, and flows in a generally westward direction for approximately 67 km (42 mi) to its confluence with the Mississippi River at Hickman, Kentucky. Smith and Sisk (1969) found Obion Creek to have “alternating series of deep, sluggish pools and swift, well-defined riffles.” Most of the stream substrates consist of clayey mud overlain by sand, gravel, and woody debris (Smith and Sisk 1969, Burr and Warren 1986). Obion Creek drains an approximately 826-$km^2$ (319-$mi^2$) area used primarily for agriculture (Burr and Warren 1986, Woods et al. 2002). The majority of the watershed is located in the Mississippi Valley Loess Plains (MVLP) Level III Ecoregion, which is characterized by gently rolling hills and irregular plains and thick loess and alluvium underlain by highly erodible unconsolidated coastal plain sediments. Few un-channelized streams can be found in this ecoregion. The lower reaches of Obion Creek are located in the Mississippi Alluvial Plain (MAP) ecoregion, a broad, flat alluvial plain with little topographic relief, with more poorly drained soils than in the MVLP. Streams in both the MVLP and MAP ecoregions are typically low gradient, with sandy to muddy substrates (Woods et al. 2002). The MVLP and MAP ecoregions are combined to form, in part, the Mississippi Valley/Interior River Lowland (MVIR) bioregion for assessment purposes (KDOW 2002).

The nonpoint source impacts to Obion Creek are well documented; the stream is listed as a second priority waterbody for Total Maximum Daily Load (TMDL) development due to nonsupport of aquatic life from sedimentation caused by streambank modification, destabilization and hydromodification, and a segment (mp 46.7–56.0) is recognized as a second priority nonpoint source impacted stream (KDOW 1996a, 1996b, 1998, 1999b). Obion Creek was channelized during several efforts beginning in the 1920s, which continued for several decades, with most of the stream above KY 307 channelized (Figure 1). A second attempt at channelization was conducted in the 1980s. Both of these alignments have since filled with sediment, and flow has been impeded with debris (Spencer and Rundle 1996, Parola and Vesely 2003). Alteration efforts have also included several attempts to remove debris (trash, logs, etc.) from the stream channel (Spencer and Rundle 1996). Debris accumulation at KY 307 extends for approximately 2.4 km (1.5 miles) upstream and has resulted in repeated flooding of the

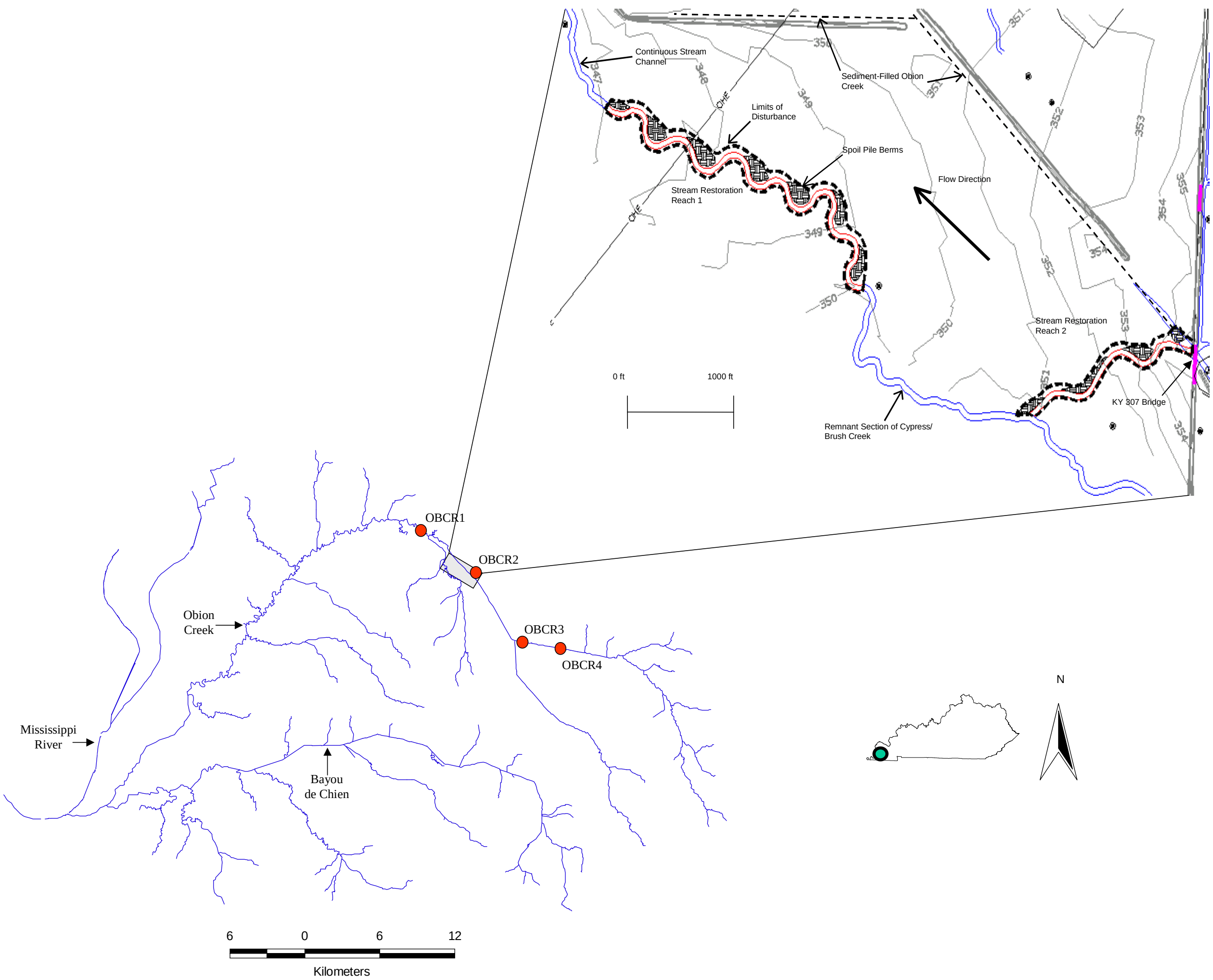


Figure 1. Obion Creek monitoring stations and the proposed restoration design in the vicinity of KY 307, which crosses Obion Creek near OBCR2. Inset shows the approximate location of the watershed in Kentucky.

roadway, persistently high groundwater levels and most of the baseflow discharge flowing in anabranched channels for a distance of approximately 3.2 km (2.0 miles) (Parola and Vesely 2003). The proposed restoration of approximately 1732 m (5684 ft) of stream channel is in a 2.0 km (1.25 mi) segment in the vicinity of KY 307 (Figure 1) on property owned by the Kentucky Department of Fish and Wildlife Resources and the Kentucky State Nature Preserves Commission. Restoration activities will involve construction of two reaches that will utilize remnants of Cypress/Brush Creek (Figure 1, Stream Restoration Reach 1) and connect the upstream Obion Creek with the new downstream alignment (Figure 1, Stream Restoration Reach 2) (Parola and Vesely 2003, W. Vesely, Univ. of Louisville, pers. comm., 5 March 2004).

Monitoring stations were located above the proposed project area in the channelized portion of Obion Creek (n = 2, stations OBCR3 and OBCR4), in an area with a natural stream pattern adjacent to the channelized stream in close proximity to the project area (n = 1, station OBCR2), and downstream of the proposed project area in a segment of Obion Creek with a natural channel that had not previously been channelized (n = 1, station OBCR1) (Figure 1, Table 1). The upstream monitoring stations (OBCR3 and OBCR4) were used as control stations to determine any observable improvements in the macroinvertebrate communities and habitat resulting from the restoration activities. The downstream station (OBCR1) was used to gauge the success of restoration efforts.

Table 1. Obion Creek monitoring station location information.

| Station ID | Location | Catchment Area ($mi^2$) | County | Latitude | Longitude |
|---|---|---|---|---|---|
| OBCR1 | At the end of Stanley Lane, in Obion Creek WMA | 185.0 | Hickman | 36.76909 | -88.91636 |
| OBCR2 | Original channel, just below KY 307 | *6.5 | Hickman | 36.74112 | -88.86921 |
| OBCR3 | Approximately 0.1 mi. above Brush Creek confluence | 70.3 | Hickman | 36.69807 | -88.83081 |
| OBCR4 | Just above KY 339, near Baltimore, KY | 60.8 | Graves | 36.6931 | -88.79030 |

* Because of the anabranched nature of Obion Creek at OBCR2, the determination of catchment area is difficult, and this value most likely does not represent the true catchment area.

*2.2 Macroinvertebrate Community Analysis*

Macroinvertebrates were collected at the monitoring locations during the spring index period (May–June) from 2000–2003 with the Rapid Bioassessment Protocols (RBPs) for low-gradient streams, which were based on recommendations of the Mid-Atlantic Coastal Plain Streams Workgroup (MACS 1996, Barbour et al. 1999, KDOW 2002). Macroinvertebrate sampling consisted of 20 jabs or kicks with a D-frame dip net (800 × 900 μm mesh) in a 100-meter reach at each sampling station, with the total area sampled approximately equal to 3.1 $m^2$; the available habitat types within the reach were sampled in proportion to their representation. For example, if root wads made up 20% of the available habitat, then 4 jabs were allocated to root wads in the 100-meter reach. The results of all 20 jabs or kicks were combined into a sieve bucket (600 μm mesh), and the sample was elutriated to remove large sticks, leaves and rocks. Samples were field processed until 1 pint or less of material remained, initially preserved in 95% ETOH, and returned to the laboratory for sorting and identification. All organisms in the sample were identified to the lowest positive taxonomic level, usually genus or species. In several instances, however, when large numbers (i.e., >100 individuals) of midge larvae (Diptera: Chironomidae) were collected, a 10% subsample was randomly chosen to facilitate identification (KDOW 2002).

### *2.3 Habitat and Physicochemical Characteristics*

Habitat at each of the monitoring stations was assessed during each sampling event using the habitat assessment protocols described in Barbour et al. (1999) and KDOW (2002). A numerical score (0–20) was assigned to each of 10 parameters designed to measure habitat quality. The scores were summed to provide an overall habitat assessment score (0–200) for each monitoring location during each monitoring event, with higher scores indicating better habitat features. Evaluated habitat parameters included epifaunal substrate/available cover (EpiFauSub), pool substrate characterization (PoolSubChar), pool variability (PoolVar), sediment deposition (SedDep), channel flow status (ChaFlowS), channel alteration (ChanAlter), channel sinuosity (ChanSin), bank stability (BankSta), bank vegetative protection (BankVegP) and riparian vegetative zone width (RipVegZW) (Barbour et al. 1999). Values for the habitat parameters BankSta, BankVegP and RipVegZW represented combinations of the scores for each bank to facilitate data analysis. Several physicochemical parameters were measured *in situ* during each sampling event with a Hydrolab® Surveyor 4/MiniSonde (Hydrolob-Hach Company, Loveland, CO). Physicochemical parameters included temperature (°C), dissolved oxygen (D.O., mg/L), percent saturation (%Sat), pH (SU) and specific conductance (μs/cm).

### *2.4 Data Analysis*

Macroinvertebrate collections were evaluated with a variety of compositional, richness and tolerance metrics, in addition to the Kentucky Macroinvertebrate Bioassessment Index (MBI). Compositional measures included a modified percent Ephemeroptera, Plecoptera and Trichoptera taxa (m%EPT; excluding the trichopteran genus *Cheumatopsyche*), percent Chironomids and Oligochaetes

(%CO) and percent primary clingers (%Cling). Genus-level richness measures included Taxa Richness (G-TR), Total Number of Individuals (G-TotInd) and the number of EPT taxa (G-EPT). The modified Hilsenhoff Biotic Index (mHBI; KDOW 2002) and the average tolerance value (AvgTolVal) for each collection were used as measures of the overall pollution tolerance of the macroinvertebrate communities (Arnwine and Denton 2000, KDOW 2002). The MBI is an aggregate index that combines the G-TR, G-EPT, mHBI, m%EPT, %CO and %Cling values into a single value that can be used to determine water quality and distinguish between reference and impaired sites, using a statewide bioregion approach. Narrative assessment ratings of water quality (e.g., Excellent, Good, Fair, Poor) are based on regional reference site MBI scores using a $25^{th}$ percentile distribution (Pond et al. 2003).

A one-way Analysis of Variance (ANOVA), Tukey's multiple-comparison procedure ($F$) (Zar 1996) and boxplots were used for between-site comparisons of the biological, habitat and physicochemical data. An unbiased version of Simpson's Index ($D$) (Pielou 1969) and Morisita's Index of Similarity ($C_{\lambda}$) (Morisita 1959) (UPGMA clustering method) were used as measures of macroinvertebrate community diversity and community similarity, respectively (Krebs 1989). Relationships between macroinvertebrate, habitat and physicochemical values were elucidated using Pearson's correlation coefficient ($r$), a Canonical Correspondence Analysis (CCA) with rare species downweighted and linear regression techniques (Palmer 1993, ter Braak 1986, Zar 1996). Habitat and physicochemical parameter values were correlated with the CCA Axis 1 values to ascertain significant relationships. Statistical analyses were conducted on genus-level macroinvertebrate data to avoid possible species-level variability (Maxted et al. 2000) and data were $\log_{10\,(x+1)}$ or $\mathrm{Log}_{10}$ transformed for analyses in order to achieve normal distributions; differences were considered significant at $\alpha \leq 0.1$ because of small sample sizes and inherent natural variability. Statistical analyses were performed with the software packages MVSP (Multi-Variate Statistical Package) (ver. 3.12d) (Kovach 1999) and SYSTAT (ver. 7.0, SPSS, Inc., Point Richmond, CA).

## 3.0 Results

### *3.1 Macroinvertebrate Community Analysis*

A total of 8,629 individuals from 228 genera were identified and enumerated from the four monitoring sites over the course of this project (Appendix A). Taxa richness values ranged from 15 (OBCR2, 2001) to 52 (OBCR1, 2000), and G-TotInd values ranged from 156 (OBCR2, 2002) to 1406 (OBCR1, 2000) (Table 2). The highest m%EPT value (67.84) was observed at OBCR4 during 2001, but the highest G-EPT value (13) was observed at OBCR1 during 2000. The highest %CO (77.41) and %Cling (36.90) values were observed at OBCR1 during 2002. The lowest mHBI value (6.46) was observed at OBCR1 during 2000, while the lowest AvgTolVal (6.21) was observed at OBCR1 during

2001. Macroinvertebrate Bioassessment Index (MBI) values ranged from 22.48 (OBCR3, 2002) to 51.70 (OBCR1, 2000) (Table 2).

The highest and lowest diversity and evenness values were observed at OBCR4 during 2000 and 2001, respectively. With macroinvertebrate counts combined for each site, OBCR1 had the highest diversity and evenness values (*D* = 0.942, evenness = 0.950) and OBCR2 had the lowest (*D* = 0.882, evenness = 0.895) (Table 3). Overall, the highest community similarity value was between OBCR3 (2003) and OBCR4 (2003) ($C_\lambda$ = 0.768) and the lowest was between OBCR2 (2002) and OBCR4 (2000) ($C_\lambda$ = 0.113) (Table 4, Figure 2a). With macroinvertebrate counts combined for each site, OBCR3 and OBCR4 were still the most similar ($C_\lambda$ = 0.739); the lowest $C_\lambda$ value (0.466) was between OBCR2 and OBCR3 (Table 4, Figure 2b).

Table 3. Obion Creek macroinvertebrate Simpson's Index (*D*) and evenness values for 2000, 2001, 2002 and 2003, and all years combined for each site.

| Site | Year | *D* | Evenness |
|---|---|---|---|
| OBCR1 | 2000 | 0.864 | 0.881 |
| | 2001 | 0.873 | 0.895 |
| | 2002 | 0.851 | 0.871 |
| | 2003 | 0.914 | 0.932 |
| | Combined | 0.942 | 0.950 |
| OBCR2 | 2001 | 0.745 | 0.782 |
| | 2002 | 0.756 | 0.791 |
| | 2003 | 0.846 | 0.864 |
| | Combined | 0.882 | 0.895 |
| OBCR3 | 2001 | 0.926 | 0.942 |
| | 2002 | 0.768 | 0.789 |
| | 2003 | 0.921 | 0.940 |
| | Combined | 0.904 | 0.914 |
| OBCR4 | 2000 | 0.934 | 0.954 |
| | 2001 | 0.743 | 0.757 |
| | 2002 | 0.789 | 0.807 |
| | 2003 | 0.930 | 0.947 |
| | Combined | 0.922 | 0.930 |

There were no between-site differences observed in G-TotInd and the MBI and substantial between-site differences (ANOVA, $0.1 < p \leq 0.2$) were observed in %CO and G-TR. Significant (ANOVA, $p \leq 0.1$) between-site differences were observed in m%EPT, %Cling, G-EPT, mHBI and AvgTolVal (Table 5). Site OBCR2 had significantly (Tukey's, $p \leq 0.1$) lower m%EPT, %Cling and G-

a

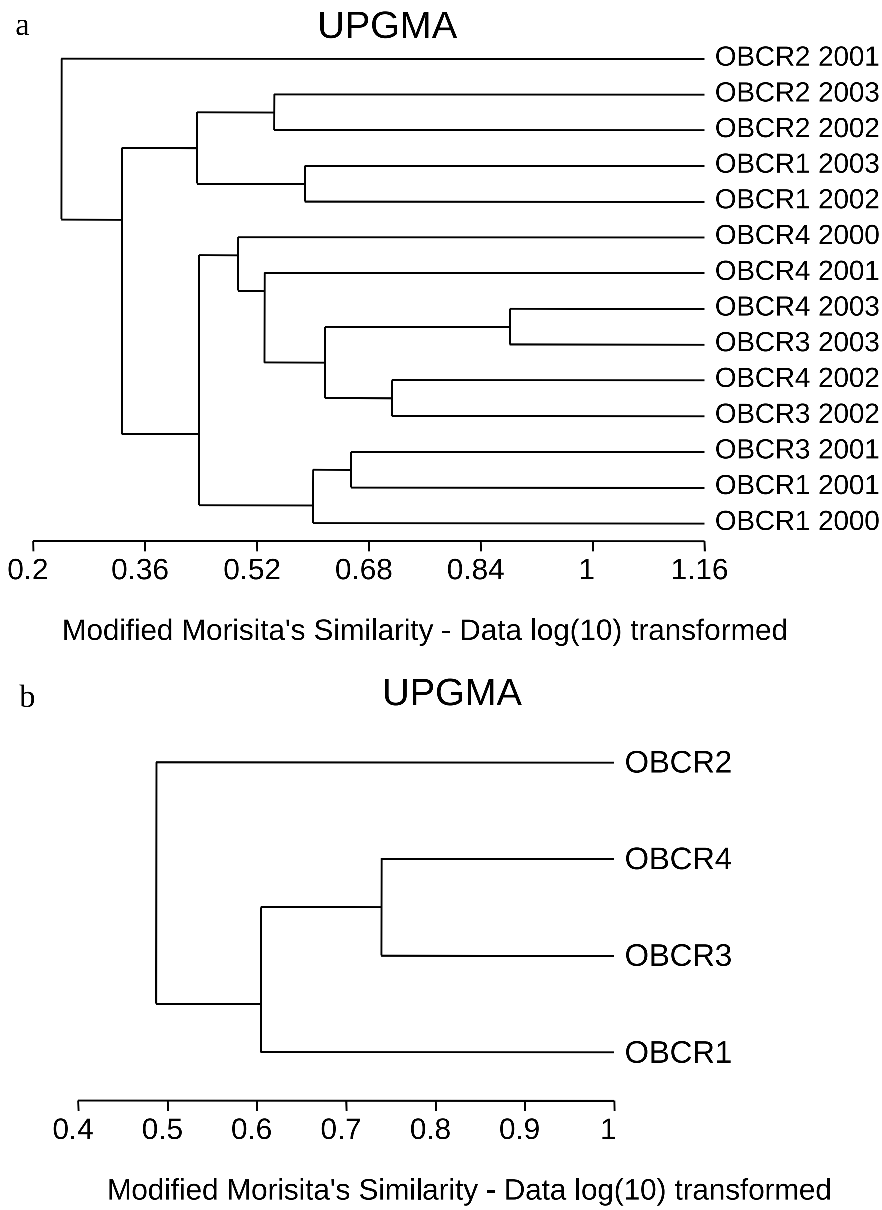


Figure 2. Dendrogram of (a) macroinvertebrate community similarity ($C_\lambda$) values for Obion Creek sites and (b) with macroinvertebrate counts combined for each site.

EPT values and significantly higher mHBI and AvgTolVal values than did OBCR1, OBCR3 or OBCR4 (Table 5, Figure 3).

*3.2 Habitat and Physicochemical Characteristics*

The highest mean BankSta (16.75) and BankVegP (16.0) values were observed at OBCR1 and OBCR2, respectively (Table 6). Site OBCR2 had the highest mean ChaFlowS value (16.00) and OBCR1 had the highest ChanAlter value (19.25); the highest mean ChanSin value (18.00) was observed at

Table 5. Obion Creek ANOVA results and average macroinvertebrate metric, habitat and physicochemical values (2000, 2001, 2002 and 2003) (d.f. = 3). Metrics with substantial between-site differences (i.e., 0.1 < p ≤ 0.2) are noted by * and those with significant between-site differences (p ≤ 0.1) are noted by **.

| | | | $\bar{x}$ | | | |
|---|---|---|---|---|---|---|
| Metric | *F* | p | OBCR1 | OBCR2 | OBCR3 | OBCR4 |
| m%EPT | 4.032 | 0.041** | 9.71 | 0.70 | 19.76 | 27.95 |
| %CO | 2.281 | 0.141* | 38.11 | 13.66 | 56.63 | 41.71 |
| %Cling | 10.352 | 0.002** | 19.65 | 1.73 | 10.64 | 14.03 |
| G-TR | 1.950 | 0.186* | 41.00 | 26.30 | 35.70 | 36.00 |
| G-TotInd | 1.237 | 0.347 | 871.50 | 447.00 | 494.30 | 597.80 |
| G-EPT | 3.346 | 0.064** | 7.50 | 1.30 | 6.30 | 5.30 |
| mHBI | 6.566 | 0.010** | 6.72 | 7.71 | 7.10 | 7.07 |
| AvgTolVal | 8.359 | 0.004** | 6.68 | 7.92 | 6.98 | 7.04 |
| MBI | 1.111 | 0.390 | 38.39 | 27.29 | 32.78 | 37.46 |
| BankSta | 2.983 | 0.083** | 16.75 | 16.67 | 15.33 | 13.00 |
| BankVegP | 1.007 | 0.429 | 15.25 | 16.00 | 12.00 | 13.50 |
| ChaFlowS | 10.199 | 0.002** | 15.75 | 16.00 | 12.00 | 8.00 |
| ChanAlter | 63.749 | ≤ 0.0001** | 19.25 | 16.33 | 12.67 | 12.25 |
| ChanSin | 9.513 | 0.003** | 18.00 | 18.00 | 7.00 | 7.75 |
| EpiFauSub | 5.234 | 0.020** | 17.25 | 8.67 | 7.00 | 8.50 |
| PoolSubChar | 2.453 | 0.123* | 15.25 | 9.33 | 13.00 | 13.00 |
| PoolVar | 2.951 | 0.085** | 16.75 | 10.67 | 11.67 | 17.25 |
| RipVegZW | 26.965 | ≤ 0.0001** | 20.00 | 20.00 | 4.33 | 14.00 |
| SedDep | 10.451 | 0.002** | 15.00 | 13.67 | 5.33 | 8.25 |
| TotHabSc | 22.821 | ≤ 0.0001** | 169.25 | 145.33 | 100.33 | 115.5 |
| %Saturation | 23.233 | ≤ 0.0001** | 60.25 | 22.30 | 94.97 | 88.50 |
| D.O. | 27.780 | ≤ 0.0001** | 5.33 | 1.95 | 8.20 | 7.84 |
| pH | 1.806 | 0.210 | 6.62 | 6.66 | 6.97 | 6.82 |
| Sp. Cond. | 5.280 | 0.019** | 100.03 | 150.67 | 99.30 | 105.58 |
| Temp. | 0.304 | 0.822 | 19.50 | 20.40 | 20.76 | 20.09 |

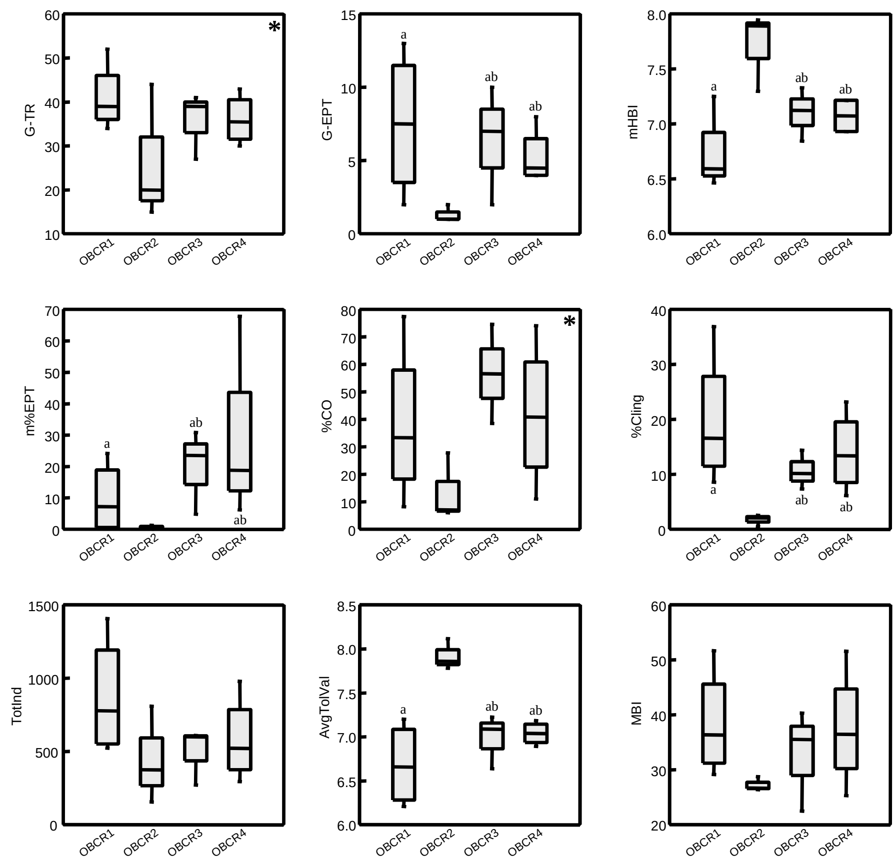


Figure 3. Obion Creek macroinvertebrate metric values. Sites with the same letters were statistically similar (Tukey's $p \le 0.1$). Metrics marked with (*) had substantial differences (ANOVA, $0.1 < p \le 0.2$).

OBCR1 and OBCR2. The highest average EpiFauSub (17.25), PoolSubChar (15.25) and SedDep values were observed at OBCR1, while the highest average RipVegZW values (20.00) were observed at both OBCR1 and OBCR2. The highest average PoolVar value (17.25) was observed at OBCR4. Total habitat score (TotHabSc) values ranged from 93 (OBCR3, 2001) to 172 (OBCR1, 2003), with OBCR1 having the highest average TotHabSc (169.25, Table 5).

There were no significant between-site differences (ANOVA, $p > 0.1$) in catchment area BankVegP and a substantial between-site difference (ANOVA, $0.1 < p \le 0.2$) in PoolSubChar. Significant (ANOVA, $p \le 0.1$) between-site differences were observed in BankSta, ChaFlowS, ChanAlter, ChanSin, EpiFauSub, PoolVar, RipVegZW, SedDep and TotHabSc (Table 5). Site OBCR4 had significantly lower (Tukey's, $p \le 0.1$) BankSta and ChaFlowS values than OBCR1 and the other sites, respectively. Sites OBCR3 and OBCR4 had statistically similar ChanAlter and ChanSin values that were significantly lower (Tukey's, $p \le 0.1$) than the values for OBCR1 and OBCR2, which had statistically similar ChanSin values. Site OBCR1 had significantly higher (Tukey's, $p \le 0.1$) EpiFauSub values than

did the statistically similar OBCR2, OBCR3 and OBCR4. Site OBCR2 had significantly lower (Tukey's, $p \leq 0.1$) PoolVar values than OBCR1 and OBCR4. Sites OBCR1 and OBCR2 had statistically similar RipVegZW values, and OBCR3 had significantly lower (Tukey's, $p \leq 0.1$) values for this parameter than did the other sites. Sites OBCR1 and OBCR2 had statistically similar values, as did OBCR3 and OBCR4, SedDep and TotHabSc values, with OBCR1 and OBCR2 having significantly higher (Tukey's, $p \leq 0.1$) values for these habitat parameters (Table 5, Figure 4).

Values for %Saturation and D.O. ranged from 12.6–101.8% and 1.1–9.0 mg/L (Table 6), respectively, with the highest mean values of both occurring at OBCR3 (Table 5). pH values ranged from 6.4–7.2 (Table 6), with the highest mean value also occurring at OBCR3 (Table 5). Specific conductance values ranged from 79.4–161.7 μs/cm (Table 6), with the lowest mean value occurring at OBCR3 (Table 5). Temperature values ranged from 17.7 ˚C (OBCR4, 2003) to 22.5 ˚C (OBCR2, 2002) (Table 6). Significant (ANOVA, $p \leq 0.1$) between-site differences were observed in %Saturation, D.O. and specific conductance (Table 5). Site OBCR2 had significantly lower (Tukey's, $p \leq 0.1$) %Saturation and D.O. values, and significantly higher specific conductance values than the other monitoring stations (Figure 5). There were no significant differences observed in temperature values.

*3.3 Macroinvertebrate, Habitat and Physicochemical Interactions*

Significant, strong correlations (i.e., $r \geq 0.300$, $p \leq 0.1$) were observed in 42 of the macroinvertebrate metric × habitat/physicochemical parameter combinations (Table 7, bolded values). Each of the macroinvertebrate metrics exhibited a significant relationship with at least one habitat or physicochemical parameter. While BankSta, RipVegZW and pH were highly correlated with several macroinvertebrate metrics (Table 7), the relationships were not significant ($p > 0.1$). Overall, the highest correlations were between catchment area and %Cling ($r = 0.848$, $p \leq 0.001$), AvgTolVal ($r = -0.845$, $p \leq 0.001$) and mHBI ($r = -0.810$, $p \leq 0.001$). The strongest correlations between the *in situ* measured habitat parameters and a macroinvertebrate metric were PoolSubChar × mHBI ($r = -0.689$, $p = 0.006$), PoolVar × G-TotInd ($r = 0.623$, $p = 0.017$), PoolVar × mHBI ($r = -0.613$, p 0.020), PoolSubChar × AvgTolVal ($r = -0.611$, $p = 0.020$) and ChanAlter × m%EPT ($r = -0.608$, $p = 0.021$).

The first 4 CCA environmental axes accounted for 53.3% of the variation observed in the macroinvertebrate communities. Axes 1 and 2 accounted for 31.3% of the variation, with Axis 1 accounting for the majority (16.5%); however, there was only a small difference between Axis 1 and Axis 4 (Table 8). Collection year ($r = 0.469$, $p = 0.090$), Catchment area ($r = -0.658$, $p = 0.011$) and the habitat parameters ChanSin ($r = 0.524$, $p = 0.055$), PoolSubChar ($r = -0.551$, $p = 0.041$) and PoolVar ($r = -0.463$, $p = 0.095$) were significantly correlated with CCA Axis 1. The physicochemical parameters %Saturation

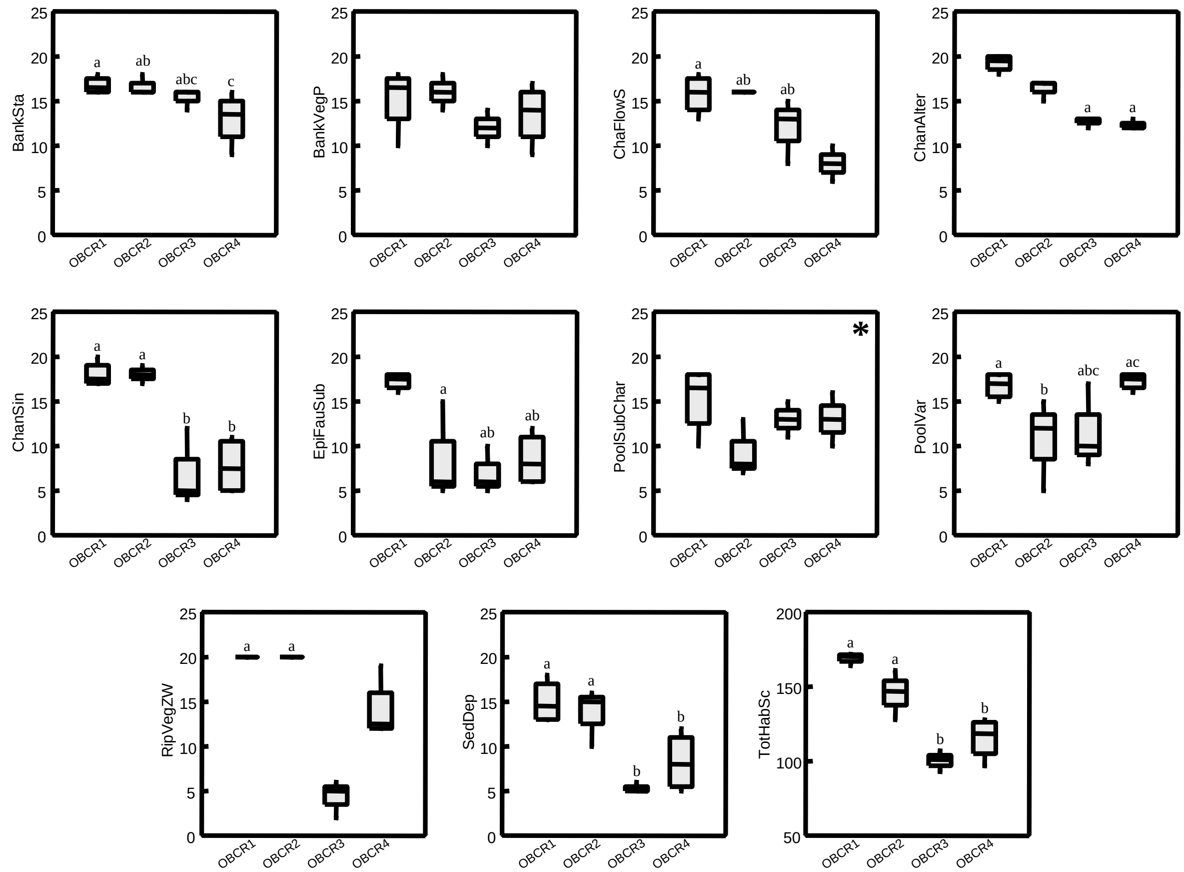


Figure 4. Obion Creek habitat parameter values. Sites with the same letters were statistically similar (Tukey's $p \leq 0.1$). Metrics marked with (*) had substantial differences (ANOVA, $0.1 < p \leq 0.2$).

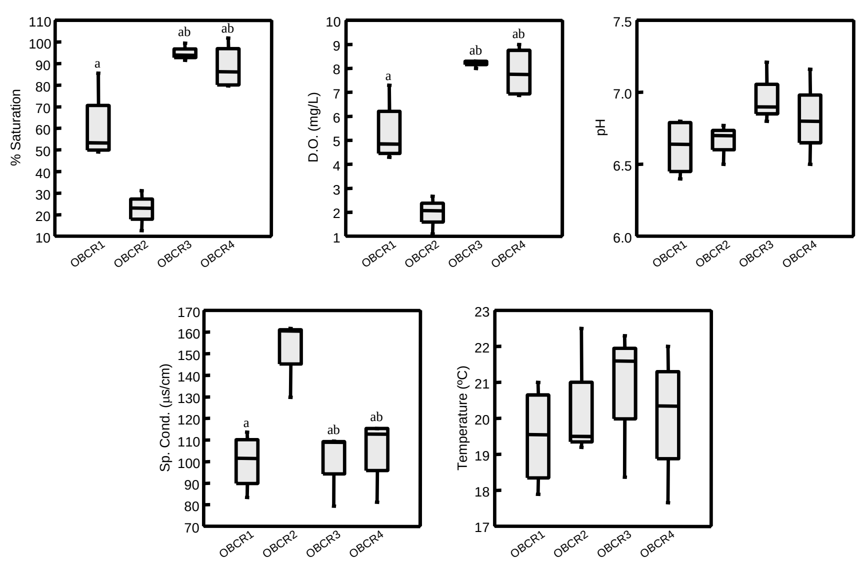


Figure 5. Obion Creek physicochemical parameter values. Sites with the same letters were statistically similar (Tukey's $p \leq 0.1$).

Table 8. Obion Creek Canonical Correspondence Analysis eigenvalues and axis case scores.

| | | Axis | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| Eigenvalues | | 0.306 | 0.275 | 0.218 | 0.192 |
| Percentage | | 16.459 | 14.804 | 11.723 | 10.346 |
| OBCR1 | 2000 | -0.542 | 0.406 | -0.225 | -0.195 |
| | 2001 | -0.638 | 0.922 | -0.178 | -0.129 |
| | 2002 | 0.476 | 0.004 | -0.594 | -0.674 |
| | 2003 | 0.557 | 0.350 | -0.529 | -0.091 |
| OBCR2 | 2001 | 0.902 | 0.727 | 0.504 | 1.538 |
| | 2002 | 1.593 | 0.520 | 0.206 | 0.068 |
| | 2003 | 0.689 | 0.169 | 0.606 | -0.347 |
| OBCR3 | 2001 | -0.840 | 0.435 | -0.058 | 0.301 |
| | 2002 | 0.155 | -0.839 | -0.834 | 0.480 |
| | 2003 | 0.003 | -0.518 | 0.219 | -0.025 |
| OBCR4 | 2000 | -0.418 | -0.462 | 0.823 | -0.343 |
| | 2001 | -0.333 | -0.210 | 0.178 | 0.710 |
| | 2002 | -0.026 | -0.613 | -0.520 | 0.116 |
| | 2003 | -0.096 | -0.584 | 0.215 | -0.139 |

($r$ = -0.605, p = 0.022), D.O. ($r$ = -0.611, p = 0.020) and specific conductance ($r$ = 0.786, p = 0.001) were also significantly correlated with the first CCA axis (Figure 6). The habitat parameters BankVegP ($r$ = 0.560, p = 0.037), ChaFlowS ($r$ = 0.732, p = 0.003), ChanAlter ($r$ = 0.615, p = 0.019), ChanSin ($r$ = 0.544, p = 0.044), EpiFauSub ($r$ = 0.574, p = 0.032), SedDep ($r$ = 0.635, p = 0.015) and TotHabSc ($r$ = 0.641, p = 0.014), as well as the physicochemical parameters %saturation ($r$ = -0.653, p = 0.011) and D.O. ($r$ = -0.665, p = 0.010), were significantly correlated with the second CCA Axis (Figure 6), which accounted for 14.8% of the variation in the macroinvertebrate communities (Table 8).

Collection year had a significant but weak effect on %CO ($R^2$ = 0.21; d.f. = 1, 12; p = 0.100), while catchment area significantly affected the G-TR ($R^2$ = 0.36; d.f. = 1, 12; p = 0.022), G-EPT ($R^2$ = 0.47; d.f. = 1, 12; p = 0.007), mHBI ($R^2$ = 0.66; d.f. = 1, 12; p < 0.001), %CO ($R^2$ = 0.22; d.f. = 1, 12; p = 0.089), %Cling ($R^2$ = 0.72; d.f. = 1, 12; p < 0.001), G-TotInd ($R^2$ = 0.22; d.f. = 1, 12; p =0.088) and AvgTolVal ($R^2$ = 0.71; d.f. = 1, 12; p < 0.001) values, though some of these represented weak relationships (e.g., %CO and G-TotInd). While not correlated with the CCA Axis 1 or Axis 2 values, collection month significantly affected G-EPT ($R^2$ = 0.29; d.f. = 1, 12; p = 0.045) and the MBI ($R^2$ = 0.46; d.f. = 1, 12; p = 0.008) values. Channel sinuosity (ChanSin) had a significant effect on m%EPT ($R^2$ = 0.34; d.f. = 1, 12; p = 0.028), and PoolVar had a significant effect on mHBI ($R^2$ = 0.38; d.f. = 1, 12; p =

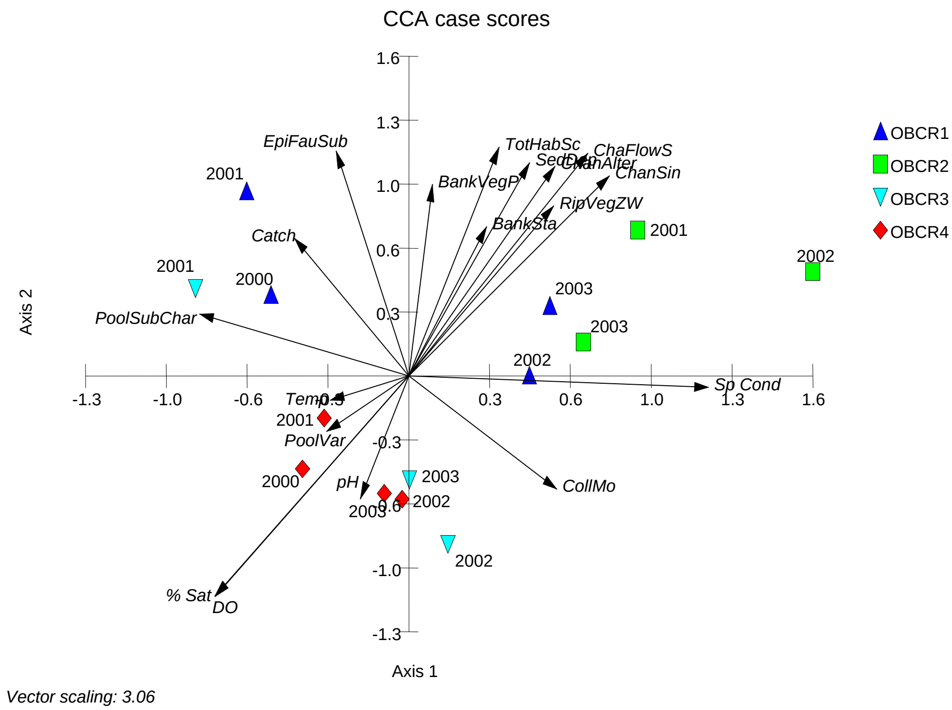


Figure 6. Biplot of Obion Creek Canonical Correspondence Analysis case scores.

0.020) and G-TotInd ($R^2$ = 0.39; d.f. = 1, 12; p = 0.017). Pool substrate characterization (PoolSubChar) had a significant effect on the G-EPT ($R^2$ = 0.32; d.f. = 1, 12; p = 0.035), mHBI ($R^2$ = 0.48; d.f. = 1, 12; p = 0.006) and AvgTolVal ($R^2$ = 0.37; d.f. = 1, 12; p = 0.020) values.

The seven habitat parameters that were significantly correlated with the second CCA Axis values had significant, but weak, affects on three macroinvertebrate metrics. Bank vegetative protection (BankVegP) ($R^2$ = 0.32; d.f. = 1, 12; p = 0.03) and SedDep ($R^2$ = 0.21; d.f. = 1, 12; p = 0.035) had significant affects on %CO and EpiFauSub had a significant affect on mHBI ($R^2$ = 0.35; d.f. = 1, 12; p = 0.03). ChaFlowS ($R^2$ = 0.27; d.f. = 1, 12; p = 0.06), ChanAlter ($R^2$ = 0.37; d.f. = 1, 12; p = 0.02) and ChanSin ($R^2$ = 0.34; d.f. = 1, 12; p = 0.03) each had significant affects on m%EPT.
Dissolved oxygen and %Saturation had significant effects on m%EPT ($R^2$ = $0.36_{D.O.}$, $0.34_{\%Sat}$; d.f. = 1, 12; p = $0.023_{D.O.}$, $0.029_{\%Sat}$), %CO ($R^2$ = 0.43; d.f. = 1, 12; p = 0.011), %Cling ($R^2$ = $0.60_{D.O.}$, $0.61_{\%Sat}$; d.f. = 1, 12; p = $0.001_{D.O.}$, < $0.001_{\%Sat}$) and AvgTolVal ($R^2$ = $0.33_{D.O.}$, $0.35_{\%Sat}$; d.f. = 1, 12; p = $0.031_{D.O.}$, $0.026_{\%Sat}$) and weak effects on G-TR ($R^2$ = 0.25; d.f. = 1, 12; $p_{D.O.}$ = 0.068, $p_{\%Sat}$ = 0.068) and G-EPT ($R^2$ = 0.25; d.f. =1, 12; p = 0.069). Specific conductance had a significant effect on G-TR ($R^2$ = 0.38; d.f. = 1, 12; p = 0.019), G-EPT ($R^2$ = 0.54; d.f. = 1, 12; p = 0.003), m%EPT ($R^2$ = 0.35; d.f. = 1, 12; p = 0.027) and the MBI values ($R^2$ = 0.33; d.f. = 1, 12; p = 0.031) and significant but weak effects on mHBI ($R^2$ = 0.28; d.f. = 1, 12; p = 0.052) and %Cling ($R^2$ = 0.27; d.f. = 1, 12; p = 0.056).

## 4.0 Discussion and Conclusions

### *4.1 Macroinvertebrate Community Analysis*

The fluctuations observed in each of the macroinvertebrate metric values over the course of the project should be considered normal given the natural fluctuations that occur in macroinvertebrate communities. Overall, all sites had Fair water quality assessment ratings (MBI = 24–47) during each year of the project, with the exception of OBCR1 (2000, Good [MBI = 48–57]), OBCR4 (2001, Good) and OBCR3 (2002, Poor [MBI = 13–23]) (Pond et al. 2003). Because the hydrologic and land-use impacts to Obion Creek affect all of the monitoring sites, several of the constituent biological metrics (e.g., m%EPT, %Cling, G-EPT and mHBI) may be more appropriate indicators of improvements in habitat than the MBI itself. While no significant differences were detected in MBI scores from the sites, this multimetric index can effectively distinguish between reference and impaired monitoring sites (Pond et al. 2003, Pond and McMurray 2002) and is the tool for using macroinvertebrates to characterize water quality in Kentucky (KDOW 2002).

Even though most of the biological metrics currently utilized in water quality assessment were originally formulated to address organic impacts (Johnson et al. 1993), they have been successfully used to assess impacts from other sources as well (e.g., McMurray and Schuster 2001, Pond and McMurray 2002). The lower values of m%EPT, %Cling and G-EPT and the higher mHBI and AvgTolVal values at OBCR2 are indicative of poorer water quality (KDOW 2002). The highest m%EPT value (67.84) observed at OBCR4 during 2001 was the result of a large number of the relatively tolerant (i.e., tolerance value ≥ 7.0, Lenat 1993, KDOW 2002) mayfly *Caenis* sp. In contrast to this, the only EPT taxa collected from OBCR2 were *Caenis* sp., and the caddisfly taxa *Cheumatopsyche* sp. and *Chimarra aterrima*. The higher mHBI and AvgTolVal values at OBCR2 were due, in part, to large abundances of the tolerant (Lenat 1993, KDOW 2002) taxa *Physella* sp., *Musculium* sp. and *Gammarus* sp. Active restoration measures have been found to positively affect measures of pollution tolerance, such as the mHBI (Gørtz 1998).

The diversity and evenness values indicated highly diverse and evenly distributed macroinvertebrate communities (i.e., ≥ 0.750) (Krebs 1989) at all sites during the course of the project. While channelized streams tend to be dominated by relatively few taxa (Laasonen et al. 1998), the two channelized sites (OBCR3 and OBCR4) consistently had high diversity values (i.e., $D \geq 0.750$) and exhibited high community similarity. This is most likely the result of large numbers, in terms of taxa richness and number of individuals, of annelids (e.g., *Slavina appendiculata*), ephemeropterans (e.g., *Baetis* spp., *Caenis* spp.), odonates (e.g., *Calopteryx* spp., *Argia* spp, *Enallagma* sp, *Ischnura* sp., *Macromia* sp) and dipterans (e.g., Chironomidae, *Prosimulium* sp.), the majority of which are considered to be tolerant organisms (e.g., Lenat 1993). Further, there was little evidence that these channelized areas were being actively maintained, which therefore allowed for the development of small areas of suitable habitat.  The macroinvertebrate community of OBCR2 was clearly different from the other sites, but was most closely related to OBCR1, since both were comparatively geomorphically similar.

*4.2 Habitat and Physicochemical Characteristics*

While the assessment of habitat using methods such as those described in Barbour et al. (1999) is subjective, training and experience of observers can reduce the variability associated with these assessments (Hannaford et al. 1997).  With the exception of OBCR2 during 2002 (Supporting, But Threatened [i.e., TotHabSc = 119–131]), TotHabSc values for OBCR1 and OBCR2 corresponded to assessment ratings of Fully Supporting designated uses (i.e., TotHabSc ≥ 132).  Habitat was found to be Supporting, But Threatened at OBCR4 during 2000 & 2001, Partially Supporting (i.e., TotHabSc = 110–188) at OBCR4 during 2002 and Not Supporting (i.e., TotHabSc ≤ 109) at OBCR3 (all years) and OBCR4 during 2003 (KDOW 2002).  Overall, the similar TotHabSc values at OBCR1 and OBCR2 were indicative of higher quality habitat, with habitat influencing biological communities (Barbour et al. 1999, KDOW 2002).

Epifaunal substrate and available cover (EpiFauSub) is a measure of the quality and quantity of natural instream cover and substrate and indicated a high degree of favorable substrate at OBCR1.  The lower PoolVar values at OBCR2 indicated that shallow pools dominated at this site, which would support fewer taxa (Hawkins et al. 1997).  Sites in the channelized portion of Obion Creek had higher amounts of sediment accumulated in pool habitat, indicating an unstable environment and decreased habitat availability.  The significantly lower ChaFlowS values at OBCR4 indicated limited suitable habitat.  The higher ChanAlter and ChanSin values at OBCR3 and OBCR4 were the result of the past channelization activities in Obion Creek and indicated fewer areas of suitable habitat.  Both OBCR1 and OBCR2 were located in forested areas and therefore had significantly higher RipVegZW values.  Vegetated riparian areas serve as important runoff buffers, erosion controls, habitat and areas of nutrient input and are usually associated with enhanced water quality (Osborne et al. 1993, Gore et al. 1995, Barbour et al. 1999).

The significantly lower %Saturation and D.O. values at OBCR2 were most likely the result of the previous channelization efforts in Obion Creek.  OBCR2 was located in the original channel of Obion Creek that had little connectivity with the engineered channel.  The stream at this location had little flow, and was represented mainly by standing pools of water that would cause the decreased %Saturation and D.O. values.  The higher %Saturation and D.O. values at OBCR3 and OBCR4 were most likely related to 1) the open canopy at these sites (pers. obs.), which would allow for overproduction of algae, and 2) small areas of gradient change creating riffle-like areas at these sites that allowed for atmospheric exchange. The proposed design for the restoration should allow for increases in %Saturation and D.O. at OBCR2.

*4.3 Macroinvertebrate, Habitat and Physicochemical Interactions*

Preserving vegetated riparian areas is critical to the success of a restoration project (Osborne et al. 1993, Gore et al. 1995). While significant differences were observed in the size of the riparian zone at the monitoring sites, RipVegZW was not significantly correlated with any of the macroinvertebrate metrics or the CCA Axis 1 values. OBCR2 is located in the general area of Restoration Reach 2, in an area of dense bottomland hardwood forest. The minimal limits of disturbance that will occur as a result of restoration (W. Vesely, Univ. of Louisville, pers. comm., 5 March 2004) should allow for the rapid establishment of an adequate, well-developed and intact riparian zone. Regardless of the presence of vegetated riparian zones, historical land-use activities can have long-term effects on biotic communities. Large-scale agricultural activities such as those in the Obion Creek watershed have been found to be a limiting factor to biotic diversity recovery following improvements in riparian areas (Harding et al. 1998) because the formation of an acceptable aquatic community is at least partially dependent upon improvements in water quality (Gore et al. 1995).

The size of the catchment area can have a profound effect on the diversity and ecology of an aquatic biological community (e.g., Vannote et al. 1980). This was observed in the relationship catchment area had with the CCA Axis 1 values and the effects on nearly all of the macroinvertebrate metrics. Because of the anabranching nature of Obion Creek, however, determination of the catchment area of OBCR2 was problematic. Restoration should provide a permanent linkage between the restored channel and upstream areas. The relationship between collection year and the CCA Axis 1 values and the effect collection year had on %CO can best be explained by the natural variability associated with biotic communities (*sensu* Inouye 1995). While Ruse (1996) found that collection month did not influence taxonomic composition, seasonality is known to be a factor in determining diversity and density in aquatic biological communities (KDOW 2002). While collection month was not correlated with the CCA Axis 1 values, it did have a significant effect on the G-EPT and MBI values.

Restoration can result in an increase in channel heterogeneity, thereby increasing the availability of suitable habitat and finally enhancing macroinvertebrate density and diversity (Friberg et al. 1994, Gore et al. 1995, Gørtz 1998). Another key to the restoration of macroinvertebrate communities is the reproduction of multiple substrate features from colonizing areas because of the diversity of habitat types that macroinvertebrates can be associated with (Gore et al. 1995, Merritt and Cummins 1996). The habitat parameters ChanSin, EpiFauSub, PoolSubChar, PoolVar and SedDep each had a significant relationship with either the CCA Axis 1 or Axis 2 values, and each are, in effect, measures of the amount of habitat available to aquatic organisms. Sinuosity (ChanSin) is directly related to the diversity of habitat types available for colonization and the ability of the stream to handle flooding and provide refugia for aquatic organisms. Epifaunal substrate and available cover (EpiFauSub) is a measure of the quality and quantity of natural instream cover and substrate. The type and condition of pool substrates (PoolSubChar) is directly related to the available habitat in pools, with streams having a variety of pool substrates being able to support more types of organisms. Streams with fewer types of pools (PoolVar) tend to support fewer types of organisms (Barbour et al. 1999). Sediment deposition (SedDep) is a measure of the amount of accumulated sediment in pools, which would limit available habitat (Waters 1995).

Since the ultimate goal of this study will be to determine improvements in macroinvertebrate community structure following restoration, improvements in water quality should not be used to determine success (Osborne et al. 1993). However, the relationships between the physicochemical parameters and the macroinvertebrates in Obion Creek cannot be overlooked because aquatic macroinvertebrate communities are directly affected by the water quality of the system in which they reside, which is directly related to land use in the upstream catchment (e.g., Harding et al. 1998, KDOW 2002). Improvements in water quality, however, may in fact be realized through channel restoration. For example, the shallow pools that dominated habitat at OBCR2 would have resulted in increased retention time and higher temperatures (Hawkins et al. 1997) and therefore decreased D.O. and %Saturation levels. An enhancement in pool variability, therefore, will allow for improved D.O. and %Saturation levels.

*4.4 Conclusions*

Objective evaluation of lotic restoration projects, using both geomorphological and biological data, is critical to the future of stream restoration (Brookes 1990, Osborne et al. 1993, Gore et al. 1995, Kondolf 1995). Few projects have done so (Davis et al. 2003), especially in the longer-term (Gore et al. 1995). In fact, there is little knowledge of the long-term effects of stream restoration (Friberg et al. 1998). Ultimately, the final goal of restoration monitoring should be to demonstrate the establishment of a stable macroinvertebrate community in the restored reaches, with stability easily determined with a taxonomic similarity index between source and reclaimed areas. Faunal restoration is achieved through enhancing habitat and colonization potential (Gore et al. 1995). It is highly possible that restoration will have a positive effect on higher trophic levels as well (Friberg et al. 1994), which may counteract the hypothesized effects channelization would have on the piscine fauna of Obion Creek (Smith and Sisk 1969).

Because of the human-induced changes to the larger-scale landscape, it may be more appropriate to attempt to return the damaged system to a present state rather than a possibly unachievable reference state (Cairns 1995), and pristine streams should serve as a point of reference rather than a goal (Osborne et al. 1993). Past land use, particularly long-term, large-scale agricultural operations, may limit recovery for decades even with high-quality riparian areas (Harding et al. 1998). To demonstrate success of restoration efforts, post-restoration monitoring should involve multiple years of sampling because of the inherent variability in macroinvertebrate populations (Inouye 1995).

Both habitat diversity and macroinvertebrate recovery rates vary. Restoration has been found to provide a greater diversity of habitats after only one year (Brookes 1990); however, it may take up to three years post-restoration to observe physical stability of the restored reach (Friberg et al. 1998). While macroinvertebrate recovery rates have been found to occur quite rapidly (Brookes 1990, Latimore 2000), durations of 2 to 3 years (Friberg et al. 1994, Purcell et al. 2002) and even up to 10–20 years (Osborne et al. 1993) of post-project evaluation may be necessary because of the natural stochastic variability inherent in macroinvertebrate communities. Barring chronic water quality impairments and in conjunction with improved habitat features, recovery rate is ultimately dependent upon the source of, and distance to, macroinvertebrate colonist pools (Gore et al. 1995). Given that the negative effects of construction on macroinvertebrate communities may be observed immediately following restoration (Friberg et al. 1994), faunal recovery should follow a predictable pattern of rapid invasion up to a climax of density and diversity and then a shift to a state of equilibrium (Gore et al. 1995).

Depending on water quality conditions and existence of nearby sources of colonizing organisms, merely restoring the physical habitat may be adequate for faunal restoration (Cairns 1995). Improvements in habitat, evaluated with the features ChanSin, EpiFauSub, PoolSubChar, PoolVar, SedDep and the total habitat score (TotHabSc) should result in improvements in the macroinvertebrate fauna in the restored reaches. Given the direct relationships between these habitat features and macroinvertebrate community diversity (Barbour et al. 1999), improvements in m%EPT, mHBI, G-TotInd, G-EPT and AvgTolVal values should be observed following the restoration of Obion Creek. Because of the inherent natural variability in biological communities, yearly post-restoration monitoring should be conducted for a minimum of four years to document improvements in the macroinvertebrate communities. It is also suggested that post-restoration monitoring be repeated following the initial sampling events at some point in the future (e.g., every 2 years for 10 years) in order to document the long-term effects that restoration of Obion Creek may have on the macroinvertebrate communities. In addition, time and resources limited the site design of this pre-restoration study. Post-restoration monitoring should employ more monitoring stations within Obion Creek in addition to monitoring established reference sites within the MVIR bioregion to increase statistical power for analyses.

**5.0 Literature Cited**


Angermeier, P.L. 1997. Conceptual roles of biological integrity and diversity. Pages 49–65 *in* J.E. Williams, C.A. Wood, and M.P. Dombeck (eds.). Watershed restoration: principles and practices. American Fisheries Society, Bethesda, MD.

Arnwine, D.H. and G.M. Denton. 2000. Development of regionally-based numerical interpretations of Tennessee's narrative biological integrity criterion. Tennessee Department of Environment and Conservation, Nashville, TN.

Babcock, W.H. 1986. Tenmile Creek: a study of stream relocation. Water Resources Bulletin 22(3):405–415.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates, and fish. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, D.C., EPA 481-D-97-002.

Bash, J.S. and C.M. Ryan. 2002. Stream restoration and enhancement projects: is anyone monitoring? Environ. Manage. 29(6):877–885.

Brookes, A. 1988. Channelized rivers: perspective for environmental management. John Wiley and Sons, New York.

Brookes, A. 1990. Restoration and enhancement of engineered river channels: some European experiences. Reg. Rivers: Res. & Manage. 5:45–56.

Burr, B.M. and M.L. Warren, Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Commission, Scientific and Technical Series Number 4. Frankfort, KY.

Cairns, J., Jr. 1995. Restoration ecology: protecting our national and global life support systems. Pages 1–12 *in* J. Cairns, Jr., (ed.). Rehabilitating damaged ecosystems, 2nd edition. Lewis Publishers, Boca Raton.

Cairns, J., Jr. and J.R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. Pages 10–27 *in* D.M. Rosenberg and V.H. Resh (eds.). Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.

Davis, N.M., V. Weaver, K. Parks, and M.J. Lydy. 2003. An assessment of water quality, physical habitat, and biological integrity of an urban stream in Wichita, Kansas, prior to restoration improvements (Phase I). Arch. Environ. Contam. Toxicol. 44:351–359.

Ehlers, R. 1956. An evaluation of stream improvement devices constructed eighteen years ago. Calif. Fish and Game 42(3):203–217.

Etnier, D.A. 1972. The effect of annual rechanneling on a stream fish population. Trans. Am. Fish. Soc. 101(2):372–375.

Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream corridor restoration: principles, processes, and practices. The Federal Interagency Stream Restoration Working Group (15 Federal agencies). GPO Item No. 0120-A; SuDocs No. A57.6/2:EN 3/PT.653. Available online at http://www.usda.gov/stream_restoration/

Friberg, N., B. Kronvang, H. Ole Hansen, and L.M. Svendsen. 1998. Long-term, habitat-specific response of a macroinvertebrate community to river restoration. Aquatic Conserv: Mar. Freshw. Ecosyst. 8:87–99.

Friberg, N., B. Kronvang, L.M. Svendsen, and H. Ole Hansen. 1994. Restoration of a channelized reach of the River Gelså, Denmark: effects on the macroinvertebrate community. Aquatic Conserv: Mar. Freshw. Ecosyst: 4:289–296.

Frissell, C.A. and R.K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. N. Am. J. Fish. Manage. 12:182–197.

Gore, J.A., F.L. Bryant, and D.J. Crawford. 1995. River and stream restoration. Pages 245–275 *in* J. Cairns, Jr. (ed.). Rehabilitating damaged ecosystems, 2nd edition. Lewis Publishers, Boca Raton.

Gørtz, P. 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquatic Conserv: Mar. Freshw. Ecosyst. 8:115–130.

Hannaford, M.J., M.T. Barbour, and V.H. Resh. 1997. Training reduces observer variability in visual-based assessments of stream habitat. J. N. Am. Benthol. Soc. 16(4):853–860.

Harding, J.S., E.F. Benfield, P.V. Bolstad, G.S. Helman, and E.B.D. Jones, III. 1998. Stream biodiversity: the ghost of land use past. Proc. Natl. Acad. Sci. 95:14843–14847.

Hawkins, C.P., J.N. Hogue, L.M. Decker, and J.W. Feminella. 1997. Channel morphology, water temperature, and assemblage structure of stream insects. J. N. Am. Benthol. Soc. 16(4):728–749.

Hynes, H.B.N. 1974. The biology of polluted waters. University of Toronto Press, Toronto.

Inouye, D.W. 1995. Variation in undisturbed plant and animal populations and its implications for studies of recovering ecosystems. Pages 357–371 *in* J. Cairns, Jr. (ed.). Rehabilitating damaged ecosystems, 2nd edition. Lewis Publishers, Boca Raton.

Johnson, R.K., T. Wiederholm, and D.M. Rosenberg. 1993. Freshwater biomonitoring using individual organisms, populations, and species assemblages of benthic macroinvertebrates. Pages 40–158 *in* D.M. Rosenberg and V.H. Resh (eds.). Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.

Karr, J.R. and E.W. Chu. 1999. Restoring life in running waters: better biological monitoring. Island Press, Washington, D.C.

Kentucky Division of Water (KDOW). 1996a. 1996 Kentucky report to Congress on water quality. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

KDOW. 1996b. 1996 303(d) list of waters for Kentucky. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

KDOW. 1998. 303(d) list of waters for TMDL development. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

KDOW. 1999a. FFY 1999 Section 319(h) grant. Division of Water, Water Quality Branch, Nonpoint Source Section, Frankfort, KY. 304 pp.

KDOW. 1999b. Kentucky nonpoint source assessment report. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

KDOW. 2002. Methods for assessing biological integrity of surface waters in Kentucky. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

KDOW. 2004. 2004 Kentucky report to Congress on water quality. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

Kondolf, G.M. 1995. Five elements for effective evaluation of stream restoration. Restor. Ecol. 3(2):133–136.

Kondolf, G.M. 1998. Lessons learned from river restoration projects in California. Aquatic Conserv: Mar. Freshw. Ecosyst. 8:39–52.

Kovach, W.L. 1999. MVSP – a multivariate statistical package for Windows, ver. 3.1. Kovach Computing Services, Pentraeth, Wales, U.K.

Krebs, C.J. 1989. Ecological Methodology. HarperCollins, New York.

Laasonen, P., T. Muotka, and I. Kivijärvi. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. Aquatic Conser: Mar. Freshw. Ecosyst. 8:101–113.

Landwehr, K. and B.L. Rhoads. 2003. Depositional response of a headwater stream to channelization, east central Illinois, USA. River Res. Applic. 19:77–100.

Latimore, J.A. 2000. Impacts of golf course construction and stream diversion on benthic invertebrates and sediment in Juday Creek, Indiana. MS Thesis, University of Notre Dame, Notre Dame, IN.

Lenat, D.R. 1993. A biotic index for the southeastern United States: derivation and list of tolerance values, with criteria for assigning water-quality rating. J. N. Am. Benthol. Soc. 12:279–290.

Maxted, J.R., M.T. Barbour, J. Gerritsen, V. Poretti, N. Primrose, A. Silvia, D. Penrose, and R. Renfrow. 2000. Assessment framework for mid-Atlantic coastal plain streams using benthic macroinvertebrates. J. N. Am. Benthol. Soc. 14:440–450.

McMurray, S.E. and G.A. Schuster. 2001. Macroinvertebrate, fish, and physicochemical differences between an acid mine drainage impacted stream and a Kentucky Wild and Scenic River. J. Ky. Acad. Sci. 62(2):125–141.

Merritt, R.W. and K.W. Cummins (eds.). 1996. An introduction to the aquatic insects of North America. Kendall/Hunt, Dubuque, IA.

Mid-Atlantic Coastal Plain Streams Workgroup (MACS). 1996. Standard operating procedures and technical basis: macroinvertebrate collection and habitat assessment for low-gradient nontidal streams. Delaware Department of Natural Resources and Environmental Conservation, Dover, Delaware.

Morisita, M. 1959. Measuring of interspecific association and similarity between communities. Mem. Fac. Sci. Kyushu Univ. Ser. E (Biol) 3:65–80.

Osborne, L.L., P.B. Bayley, L.W.G. Higler, B. Statzner, F. Triska, and T.M. Iversen. 1993. Restoration of lowland streams: an introduction. Freshwat. Biol. 29:187–194.

Palmer, M.W. 1993. Putting things in even better order: the advantages of canonical correspondence analysis. Ecology 74(8):2215–2230.

Parola, A.C., Jr., and W. Vesely. 2003. Obion Creek stream corridor restoration US EPA 319 demonstration project: project description report. Prepared for The Jackson Purchase RC&D Foundation, Inc., Natural Resources Conservation Service, Clinton, Kentucky. University of Louisville, Louisville, KY.

Pielou, E.C. 1969. An introduction of mathematical ecology. Wiley, New York.

Pond, G.J., S.M. Call, J.F. Brumley, and M.C. Compton. 2003. The Kentucky macroinvertebrate bioassessment index: derivation of regional narrative ratings for assessing wadeable and headwater streams. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

Pond, G.J. and S.E. McMurray. 2002. A macroinvertebrate bioassessment index for headwater streams of the eastern coalfield region, Kentucky. Environmental and Public Protection Cabinet, Department for Environmental Protection, Frankfort, KY.

Purcell, A.H., C. Friedrich, and V.H. Resh. 2002. An assessment of a small urban stream restoration project in northern California. Restor. Ecol. 10(4):685–694.

Rosgen, D. 1996. Applied river morphology. Wildland Hydrology, Pagosa Springs, CO.

Ruse, L.P. 1996. Multivariate techniques relating macroinvertebrate and environmental data from a river catchment. Wat. Res. 30(12):3017–3024.

Smith, P.L. and M.E. Sisk. 1969. The fishes of west Kentucky. II. The fishes of Obion Creek. Trans. Ky. Acad. Sci. 30:60–68.

Spencer, W.E. and J. Rundle. 1996. Status, problems and future projections for the Obion Creek floodplain, Hickman County, Kentucky. Prepared for the Kentucky Department of Fish and Wildlife Resources, Frankfort, Kentucky. Department of Biological Sciences and the Hancock Biological Station, Murray State University, Murray, KY.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67:1167–1179.

U.S. Army Corps of Engineers (USACOE). 1995. Water resources development in Kentucky. Louisville District, Louisville, KY.

U.S. Environmental Protection Agency (USEPA). 1997. Monitoring guidance for determining the effectiveness of nonpoint source controls. U.S. Environmental Protection Agency, Office of Water, Washington, D.C., EPA 841-B-96-004.

USEPA. 2000. 2000 water quality report to Congress. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. Available online at: http://www.epa.gov/305b/2000report/.

Vannote, R.L., G.W. Minshall, K.W. Cummins, J.R. Sedell, and C.E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130–137.

Waters, T.F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7, Bethesda, Maryland.

Woods, A.J., J.M. Omernik, W.H. Martin, G.J. Pond, W.M. Andrews, S.M. Call, J.A. Comstock, and D.D. Taylor. 2002. Ecoregions of Kentucky (color poster with map, descriptive text, summary tables, and photographs): Reston, VA, U.S. Geological Survey (map scale 1:1,000,000).

Zar, J.H. 1996. Biostatistical Analysis, 3rd edition. Prentice Hall, NJ.

Appendix A

Obion Creek pre-restoration macroinvertebrate taxa

| | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| **Gastropoda** | | | | | | | | | | | | | | |
| Ancylidae: | | | | | | | | | | | | | | |
| *Ferrissia rivularis* | | | 5 | | | | | | | | | | | |
| Lymnaeidae: | | | | | | | | | | | | | | |
| *Lymnaea sp.* | | | | | | | 1 | | | | | | | |
| Physidae: | | | | | | | | | | | | | | |
| *Physella sp.* | 14 | 63 | 17 | 8 | 1 | 28 | 289 | 2 | 23 | 10 | 2 | 1 | 6 | 13 |
| Planorbidae: | | | | | | | | | | | | | | |
| *Gyraulus sp.* | | | | 2 | | 1 | 9 | | | 1 | | | | |
| *Helisoma trivolis* | | | | | | 2 | | | | | | | | |
| **Pelecypoda** | | | | | | | | | | | | | | |
| Corbiculidae: | | | | | | | | | | | | | | |
| *Corbicula fluminea* | 21 | 17 | 2 | 23 | | | | | | | | | | |
| Sphaeriidae: | | | | | | | | | | | | | | |
| *Musculium sp.* | | | | 229 | 169 | 64 | 21 | | | | | | | |
| *Pisidium sp.* | | 5 | | | | | | | | | | | | |
| *Sphaerium sp.* | | | 6 | 60 | | 33 | 66 | | 1 | 3 | | | 1 | |
| **Annelida** | | | | | | | | | | | | | | |
| Enchytraeidae: | | | | 2 | | | | | | 2 | | | | 4 |
| Erpobdellidae: | | | | | | | | | | | | | | |
| *Dina parva* | | | | | | | 22 | | | | | | | |
| *Mooreobdella sp.* | | | 4 | | | 5 | | | | | | | | |
| Glossiphoniidae: | 1 | | | | | | | | | | 1 | 1 | | |
| *Placobdella sp.* | | | | | | | | | | | | | 1 | |
| Lumbricidae: | | | 1 | 2 | | | 1 | | | 1 | | | 5 | 1 |
| Lumbriculidae: | 15 | 4 | | | | | | 11 | | | | | | |
| *Eclipidrilus sp.* | | | | | | | | | | | | 1 | | |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| Naididae: | | | | | | | | | | | | | | |
| *Slavina appendiculata* | | | | | | | 6 | | | 9 | | | | 28 |
| Planariidae: | | | | | | | 4 | | | | | | | |
| *Branchiura sowerbyi* | | | | 3 | | 2 | | | | | | 1 | | |
| *Limnodrilus sp.* | | | | 6 | 12 | 2 | 16 | | | 1 | | | | 7 |
| UIW/OCS sp. | | | 6 | | | | 18 | | | | | | | |
| UIWCS sp. | | | | | 1 | | | | | | | | | |
| **Ephemeroptera** | | | | | | | | | | | | | | |
| Baetidae: | | | | | | | | | | | | 1 | | |
| *Acerpenna sp.* | 41 | | | | | | | | | | | | | |
| *Baetis sp.* | 8 | 7 | | 2 | | | | 6 | | | 10 | | | |
| *Baetis intercalaris* | | | | | | | | | | | | | 1 | |
| *Baetis tricaudatus* | | | | | | | | | | 2 | | | 1 | |
| *Centroptilum sp.* | | | | | | | | 5 | | | | | | |
| *Plauditus sp.* | 2 | 2 | | | | | | | 9 | 9 | | | | 11 |
| *Pseudocloeon sp.* | 25 | | | | | | | | | 1 | | | | 1 |
| Caenidae: | | | | | | | | | | | | | | |
| *Caenis sp.* | | | | | | | 1 | | 20 | 130 | | | 34 | 178 |
| *Caenis amica* | | | | | | | | | | | | 9 | | |
| *Caenis latipennis* | 256 | 31 | | | | | | 59 | | | 40 | 140 | | |
| *Caenis punctata* | | | | | 5 | | | | | | | 131 | | |
| Ephemeridae: | | | | | | | | | | | | | | |
| *Hexagenia sp.* | | 2 | | 3 | | | | | | | | | | |
| Heptageniidae: | | | | | | | | | | | 1 | | | |
| *Leucrocuta sp.* | | | | | | | | | | | | 1 | | |
| *Stenacron sp.* | | | 1 | | | | | | | | | | | |
| *Stenacron interpunctatum* | 2 | | | 2 | | | | | | | | | | |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| *Stenacron pallidum* | | 4 | | | | | | | | | | | | |
| *Stenonema sp.* | | | | | | | | | | | | 4 | | |
| *Stenonema femoratum* | 1 | | | | | | | | | | | 1 | | |
| *Stenonema modestum* | | 7 | | | | | | 8 | | | | | | |
| *Stenonema vicarium* | | | | | | | | | | | | 1 | | |
| Leptophlebiidae: | | | | | | | | | | | | | | |
| *Paraleptophlebia sp.* | 1 | | | | | | | | | | | | | |
| **Odonata** | | | | | | | | | | | | | | |
| Aeshnidae: | | | | | | | | | | | | | | |
| *Basiaeschna janata* | | | | | | | | | | | | 2 | | |
| *Boyeria sp.* | | | | | | | | | 3 | | | | 1 | |
| *Nasiaeschna pentacantha* | | | | 1 | | | | | | | | | | |
| Calopterygidae: | | | | | | | | | | | | | | |
| *Calopteryx sp.* | | | 2 | 8 | | | | | | 7 | | | | 2 |
| *Calopteryx dimidiata* | 15 | 7 | | | | | | 23 | | | 29 | | | |
| *Calopteryx maculata* | | | | | | | | | | | | 15 | | |
| Coenagrionidae: | | | | | | | | | | | | | | |
| *Amphiagrion saucium* | | | | | | | | | | | 17 | | | |
| *Argia sp.* | 14 | 16 | | 23 | | | | 25 | 4 | 17 | | | 2 | 18 |
| *Argia fumipennis violacea* | | | | | | | | | | | | 4 | | |
| *Argia tibialis* | | | | | | | | | | | | 8 | | |
| *Enallagma sp.* | | 2 | | 2 | | | 2 | | | 7 | 12 | | | 35 |
| *Enallagma basidens* | | | | | | | | | | | | 20 | | |
| *Ischnura sp.* | | | 2 | | | 1 | | | 14 | 3 | | | 5 | 14 |
| Gomphidae: | | | | | | | | | | | | | | |
| *Dromogomphus sp.* | | 1 | | | | | | | | | 2 | | | |
| *Gomphus sp.* | 1 | | 2 | 3 | | | | | 1 | 1 | | | 1 | 2 |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| *Progomphus sp.* | 8 | | 3 | | | | | | | | | | 1 | |
| *Progomphus obscurus* | | 1 | | | | | | 3 | | | 1 | | | |
| Lestidae: | | | | | | | | | | | | | | |
| *Lestes sp.* | 1 | | | | | | | | | | | | | |
| Libellulidae: | | | | | 1 | | | | | | | | | |
| *Erythemis simplicicollis* | | | | | | | | | | 1 | | | | |
| *Libellula sp.* | 9 | | 1 | | 1 | | 16 | 1 | 1 | 3 | | 2 | 1 | 6 |
| *Pachydiplax longipennis* | | | | | | | 2 | | | | | | | |
| *Somatochlora sp.* | | | | | | 1 | 1 | | | | | | | |
| Macromiidae: | | | | | | | | | | | | | | |
| *Macromia sp.* | | 4 | | 1 | | | 1 | 4 | | 2 | 6 | 10 | 1 | 4 |
| **Plecoptera** | | | | | | | | | | | | | | |
| Nemouridae: | | | | | | | | | | | | | | |
| *Amphinemura sp.* | | | | | | | | 1 | | | | | | |
| Perlidae: | | | | | | | | | | | | | | |
| *Perlesta sp.* | 1 | | | | | | | 1 | | 1 | 3 | 8 | | |
| **Hemiptera** | | | | | | | | | | | | | | |
| Corixidae: | | | | | 2 | | | | | | | | | |
| *Trichocorixa sp.* | | | | | | 1 | | | | | | | | |
| Hydrometridae: | | | | | | | | | | | | | | |
| *Hydrometra sp.* | | | 1 | 1 | | | | | | | | | | |
| Veliidae: | | | | | | | | | | | | | | |
| *Microvelia sp.* | 2 | | | | | | | | | | | 1 | 1 | 1 |
| **Megaloptera** | | | | | | | | | | | | | | |
| Corydalidae: | | | | | | | | | | | | | | |
| *Chauloides sp.* | | | 1 | | | 3 | 3 | | 2 | 1 | | | 1 | |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| Sialidae: | | | | | | | | | | | | | | |
| *Sialis sp.* | 1 | | | | | | | 1 | 1 | | | | | |
| **Trichoptera** | | | | | | | | | | | | | | |
| Dipseudosidae: | | | | | | | | | | | | | | |
| *Phylocentropus sp.* | | 4 | | | | | | | | | | | | |
| Hydropsychidae: | | | | | | | | | | | | | | |
| *Cheumatopsyche sp.* | 159 | | 60 | 135 | | | 4 | 3 | | 45 | 21 | | 16 | 37 |
| *Hydropsyche sp.* | | | | 2 | | | | | | | | | | |
| *Hydropsyche betteni* | | | | | | | | | | | | | 1 | |
| Hydroptilidae: | | | | | | | | | | | | | | |
| *Hydroptila sp.* | | | | | | | | | | 1 | | | | |
| Leptoceridae: | | | | | | | | | | | | | | |
| *Nectopsyche sp.* | | | | | | | | 1 | | | | | | |
| *Oecetis avara* | | 2 | | | | | | 2 | | | | | | |
| *Setodes sp.* | | | | | | | | | | | | 1 | | |
| *Triaenodes sp.* | | | | | | | | | | | | 9 | | |
| *Triaenodes flavescens* | | 1 | | | | | | | | | | | | |
| *Triaenodes ignitus* | 1 | 1 | | | | | | 1 | | | | | | |
| Limnephilidae: | | | | | | | | | | | | | | |
| *Pycnopsyche sp.* | 1 | 10 | | | | | | | | | | | | |
| Philopotamidae: | | | | | | | | | | | | | | |
| *Chimarra aterrima* | | | | | | 1 | | | | | | | | |
| Polycentropodidae: | | | | | | | | | | | | | | |
| *Nyctiophylax sp.* | | | | | | | | | | | | 2 | | |
| Psychomyiidae: | | | | | | | | | | | | | | |
| *Lype diversa* | 1 | | | | | | | | | | | | | |

| | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| **Coleoptera** | | | | | | | | | | | | | | |
| Dryopidae: | | | | | | | | | | | | | | |
| *Helichus basalis* | | | | | | | | | | | | | 1 | |
| Dytiscidae: | | | | | | | | | | | | | | |
| *Agabus sp.* | | | | | | | 1 | | | | 1 | | | |
| *Celina sp.* | | | | | 7 | | | | | | | | | |
| *Copelatus sp.* | | | 1 | | | | | | | | | | | |
| *Coptotomus sp.* | | | | | | | 1 | | | | | | | |
| *Coptotomus loticus* | 1 | | | | | | | | | | | | | |
| *Hydroporus sp.* | | | | | | | | | | | | 3 | | |
| *Hydrovatus sp.* | 1 | | | | | | | | | | 3 | | | |
| *Hygrotus sp.* | | | | | | | | | | 1 | | | | |
| *Ilybius sp.* | | | | | | | | | | | | 1 | | |
| *Neoporus sp.* | | | | | | | 5 | | | | 1 | | 1 | |
| *Uvarus sp.* | | | | | | | | | | | | | | 1 |
| Elmidae: | | | | | | | | | | | | | | |
| *Ancyronyx variegatus* | | | 1 | 1 | | | | | 3 | 2 | | | | 3 |
| *Dubiraphia sp. (larvae)* | 2 | | | | | | | 1 | | | 1 | | | |
| *Dubiraphia bivittata* | | | | | | | | | | | | | | 5 |
| *Dubiraphia vittata* | 3 | | 4 | | | | | | 9 | 4 | 4 | 5 | 9 | |
| *Macronychus glabratus* | | | | | | | | | | | | 6 | | |
| *Optioservus ovalis* | | 3 | | | | | | 2 | | | | | | |
| *Stenelmis sp. (larvae)* | 2 | 6 | | | | | | | | | | | | |
| *Stenelmis decorata* | | 1 | | | | | | | | | | | | |
| *Stenelmis sandersoni* | | | 5 | 3 | | | | | | | | | 1 | |
| Gyrinidae: | | | | | | | | | | | | | | |
| *Dineutus sp.* | 6 | | | | | | | 1 | | | | | | |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| *Gyretes sp.* | 1 | | | | | | | | | | | | | |
| *Gyrinus sp. (larvae)* | | | | | | | | | | | | 1 | | |
| Haliplidae: | | | | | | | | | | | | | | |
| *Peltodytes sp.* | | | | | | | | 1 | | 2 | | | | |
| Hydrophilidae: | | | | | | 1 | | | | | | | | |
| *Berosus sp.* | | | | 1 | | | | | | | | | | |
| *Helocombus sp.* | | | | | | | 1 | | | | | | | |
| *Tropisternus sp. (larvae)* | 1 | | | | | | | | | | | | | |
| Scirtidae: | | | | | | | | | | | | | | |
| *Cyphon sp.* | | | | | | | 2 | | | | | | | 1 |
| **Diptera** | | | | | | | | | | | | | | |
| Ceratopogonidae: | | | | | | | | | | | | | | |
| *Bezzia/Palpomyia gr.* | | | | | | | 2 | | | | | | | |
| *Monohelea sp.* | | | | | | | 2 | | | | | | | |
| *Probezzia sp.* | | 1 | | | | | | | | | | | | 1 |
| Chironomidae: | 9 | 32 | 22 | 5 | | | 14 | 9 | 18 | 45 | | | 23 | 39 |
| *Ablabesmyia sp.* | 8 | | | | | | | | | | | 2 | | |
| *Ablabesmyia mallochi gr.* | | 12 | | 10 | | | 10 | 4 | | | | 2 | | 10 |
| *Apedilum sp.* | | 20 | | | | | | | | | | | | |
| *Brillia sp.* | | | | | | | | | | | | 1 | | |
| *Chironomus sp.* | | | | | | 1 | 10 | 8 | 10 | 40 | 21 | 3 | 70 | 30 |
| *Conchapelopia sp.* | | | | 90 | | | | | | | | | | |
| *Cricotopus sp.* | | | | | | | | | 20 | | | | 20 | |
| *Cryptochironomus sp.* | | 12 | 10 | 20 | | | 30 | | | | 1 | | | |
| *Dicrotendipes sp.* | 4 | | | | | | | | | | | 10 | 20 | |
| *Dicrotendipes fumidus* | | | | 10 | | | | | | | | | | 50 |
| *Dicrotendipes modestus* | | | | | | | 10 | | | 20 | | | | |

| | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| *Dicrotendipes nervosus* | | | | | | | | 4 | | | | | | |
| *Eukiefferiella sp.* | | | | | | | | | | | 3 | | | |
| *Glyptotendipes sp.* | | | | | | | 20 | | | | 3 | | | |
| *Labrundinia pilosella* | | | 10 | | | | | | | | | | | |
| *Micropsectra sp.* | 28 | | | | | | | | | | | | | |
| *Micropsectra polita* | | | | | | | | | | | | | | 10 |
| *Microtendipes sp.* | 4 | | 20 | 90 | | | | | | | | | | |
| *Natarsia sp.* | | | | | | | | | | | | 1 | 10 | |
| *Parachironomus sp.* | | | | | | | 10 | | | | 1 | 7 | | |
| *Parachironomus tenuicaudata gp.* | | | | | | | | | | | | | | 30 |
| *Paratanytarsus sp.* | | | 140 | 40 | 2 | | 10 | | | 30 | | | | 50 |
| *Phaenopsectra sp.* | | | | | | | | | | | 1 | 1 | | |
| *Phaenopsectra obediens gp.* | | | | | | | | | | 10 | | | | |
| *Phaenopsectra/Tribelos sp.* | | | | | | | 10 | | | | | | | |
| *Polypedilum sp.* | | | | | | | | | | | 2 | 14 | | |
| *Polypedilum fallax* | | | | | | | | | | | | | | 10 |
| *Polypedilum flavum* | 24 | | 40 | 70 | | | | 12 | 10 | | | | | 10 |
| *Polypedilum scalaenum gr.* | 4 | 4 | | 10 | | | | | | | | | | |
| *Polypedilum tritum* | | | 130 | 10 | | 5 | 30 | 16 | 370 | 70 | | | 290 | 110 |
| *Potthastia longimanus* | | | | | | | | | | | | | | 20 |
| *Procladius sp.* | | | | | 7 | | | 12 | 10 | 30 | | 6 | | 20 |
| *Psectrotanypus dyari* | | | | | | | 10 | | | | | | | |
| *Rheocricotopus sp.* | | 12 | | | | | | 4 | | | | | | |
| *Rheotanytarsus sp.* | 12 | 24 | | | | | | 4 | | | 1 | | | |
| *Stenochironomus divinctus* | | | 10 | | | | | | | | | | | |
| *Stictochironomus devinctus* | | | | | | | 20 | | | 40 | 66 | | | 10 |
| *Tanytarsus sp.* | | | 10 | | | | | | 10 | | | | | |

| Taxa | OBCR1 | | | | OBCR2 | | | OBCR3 | | | OBCR4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2001 | 2002 | 2003 | 2000 | 2001 | 2002 | 2003 |
| *Thienemannimyia gr.* | 8 | 4 | 50 | | 1 | 1 | | 1 | | 50 | 2 | 1 | | 60 |
| *Tribelos atrum* | | 24 | | | | | | | | | | | | |
| *Tribelos fuscicorne* | | | | | | | | 20 | | | | | | |
| *Xylotopus par* | | | | 10 | | | | | | | | | | |
| Culicidae: | | | | | | | | | | | | | | |
| *Anopheles sp.* | | | | | | | | | 1 | | | | | |
| Empididae: | | | | | | | | | | | | | | |
| *Hemerodromia sp.* | | | 2 | | | | | | | | | | | |
| Ephydridae: | | | | | | | | | | | | | | |
| *Ephydra sp.* | | | | | | | 1 | | | | | | | |
| Muscidae: | | | | | | | | | | | | | | |
| *Limnophora sp.* | | | | | | | | | 1 | | | | 2 | |
| Psychodidae: | | | | | | | | | | | | | | |
| *Pericoma sp.* | | | | | | | | | | | | | | 1 |
| *Psychoda sp.* | | | | | | | | 4 | | | | | | 1 |
| *Psychoda alternata* | 1 | | | | | | | | | | | | | |
| Simuliidae: | | | | | | | | | | | | | | |
| *Prosimulium sp.* | 4 | | | | | | | | 42 | 1 | | | 20 | 47 |
| *Simulium sp.* | 15 | | 2 | | | | | 1 | 5 | 3 | 16 | | 15 | 85 |
| Tabanidae: | | | | | | | | | | | | | | |
| *Chrysops sp.* | | | | | | | | | | 1 | | | | |
| *Tabanus sp.* | | | | 1 | | | 3 | | | | | 2 | | |
| Tipulidae: | | | | | | | | | | | | | | |
| *Limonia sp.* | | | | | | | | | | | | | | 1 |
| *Tipula sp.* | | 1 | 1 | | | | 3 | | 2 | 1 | | | | 6 |

| Taxa | OBCR1 2000 | OBCR1 2001 | OBCR1 2002 | OBCR1 2003 | OBCR2 2001 | OBCR2 2002 | OBCR2 2003 | OBCR3 2001 | OBCR3 2002 | OBCR3 2003 | OBCR4 2000 | OBCR4 2001 | OBCR4 2002 | OBCR4 2003 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Amphipoda** | | | | | | | | | | | | | | |
| Asellidae: | | | | | | | | | | | | | | |
| *Caecidotea sp.* | | 2 | 3 | 51 | | | | | 1 | | | 2 | 2 | 2 |
| *Lirceus fontinalis* | 68 | | | 6 | | | | 2 | | | | | | |
| Crangonyctidae: | | | | | | | | | | | | | | |
| *Crangonyx sp.* | 173 | | | | | | | | 2 | | | | | |
| Gammaridae: | | | | | | | | | | | | | | |
| *Gammarus sp.* | 370 | 162 | | 21 | 122 | | 83 | | | | | | 2 | |
| Hyalellidae: | | | | | | | | | | | | | | |
| *Hyalella azteca* | 47 | 1 | | 1 | | 1 | 2 | 4 | 7 | | 16 | 7 | 25 | 3 |
| **Decapoda** | | | | | | | | | | | | | | |
| Cambaridae: | | | | | | | | | | | | | | |
| *Cambarus diogenes* | | | | 1 | | | | 3 | | | | 5 | | |
| *Cambarus distans* | | | | | 26 | | | | | | | | | |
| *Orconectes sp.* | | | | 8 | | | | | | | | | | |
| *Procambarus sp.* | | | 5 | | | 2 | | | | | | | | 1 |
| *Procambarus acutus acutus* | | | | | 7 | | 36 | | | | 7 | | | |
| *Procambarus clarkii* | 9 | 9 | | | 12 | | | 1 | | 3 | | | | |
| Palaemonidae: | | | | | | | | | | | | | | |
| *Palaemonetes kadiakensis* | | 2 | | | | | | 1 | | | | | | |