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Detection of Temporal Trends in Ohio River Fish Assemblages Based on Lockchamber Surveys (1957–2001)

JEFF A. THOMAS[1] AND ERICH B. EMERY
Ohio River Valley Water Sanitation Commission (ORSANCO),
5735 Kellogg Avenue, Cincinnati, Ohio 45228, USA

FRANK H. MCCORMICK
USDA Forest Service, Pacific Northwest Research Station, Olympia Forestry Sciences Laboratory
Olympia, Washington 98512, USA

U.S. Environmental Protection Agency, National Exposure Research Laboratory,
26 West Martin Luther King Drive, Cincinnati, Ohio 45268, USA

Abstract.—The Ohio River Valley Water Sanitation Commission (ORSANCO), along with cooperating state and federal agencies, sampled fish assemblages from the lockchambers of Ohio River navigational dams from 1957 to 2001. To date, 377 lockchamber rotenone events have been conducted, resulting in the collection of nearly three million fishes, representing 116 taxa, including 7 hybrids, in 19 families. We observed significant temporal trends in Ohio River fish riverwide at the assemblage, guild, and species levels. Modified index of well-being (MIWB) scores and changes in guild structure indicated significantly ($p < 0.05$) improving fish assemblages throughout the Ohio River. Quantile regression of the abundance of individual species by year revealed significant declines ($p < 0.05$) in populations of several pollution-tolerant species (e.g., *Ameiurus* spp., goldfish *Carassius auratus*) with time, while some intolerant species (e.g., smallmouth redhorse *Moxostoma breviceps,* smallmouth bass *Micropterus dolomieu,* and mooneye *Hiodon tergisus*) have increased in recent years. In all, 40 of the 116 taxa collected in the lockchamber surveys changed significantly over time. Sixteen species did not change. Sixty species could not be analyzed either because of incomplete data or insufficient abundance. Fish assemblage metrics that would be expected to decrease with improving conditions in the Ohio River (percent tolerant individuals, percent nonindigenous individuals, and percent detritivore individuals) also declined ($p < 0.05$). These changes coincide with marked improvement of the water quality in the Ohio River over the last 50 years, particularly in the aftermath of the Clean Water Act (1972). Some species and metric responses may also be due to the replacement of the 50 wicket dams by the construction of 18 high-lift dams.

Introduction

The Ohio River basin (Figure 1) has undergone dramatic changes since the early settlement period (1781–1803). The first Europeans found a beautiful, free-flowing, clear river buffered by hardwood forests and an abundance of wetlands (Trautman 1981; Pearson and Pearson 1989). Sycamores 3–5 m in circumference at 1 m high were common in the upper section of the river (Cramer 1824). As the land was settled over the next 100 years, the

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[1] Corresponding author: jthomas@orsanco.org

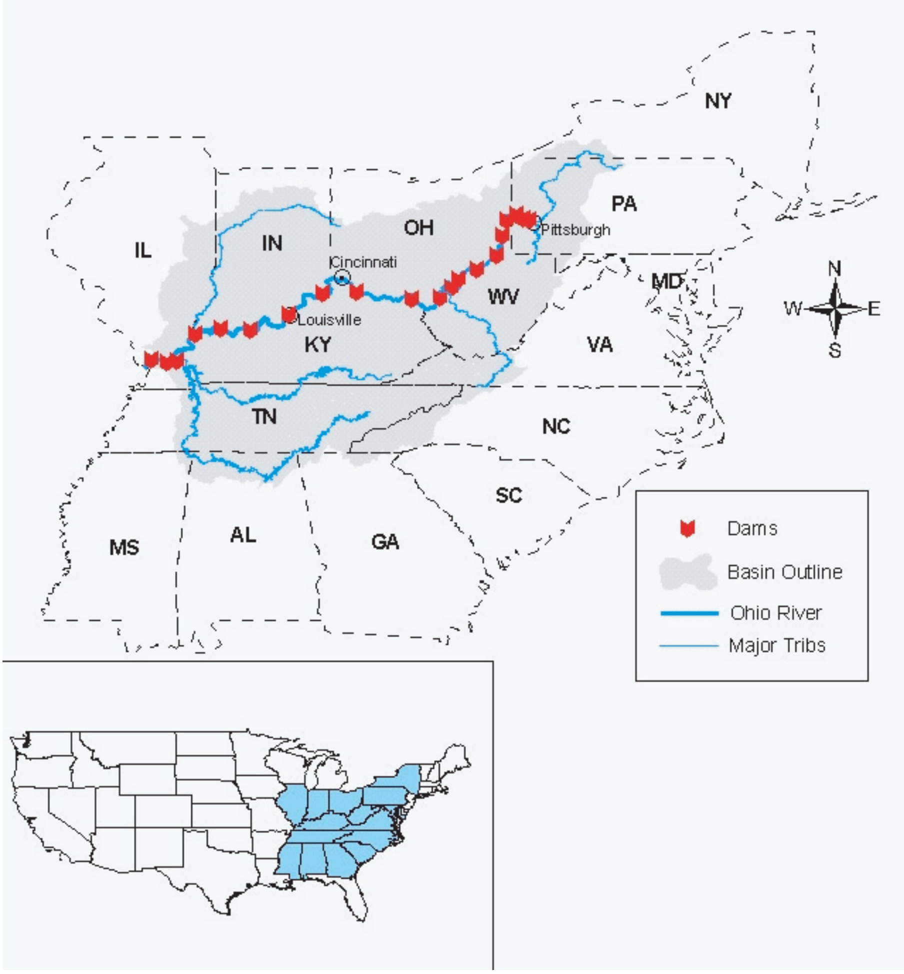

Figure 1.—The Ohio River showing the location of the 20 navigational dams, major tributaries, and three major metropolitan areas (Pittsburgh, Cincinnati, and Louisville).

entire basin was heavily logged and many of the wetlands along the river were drained, causing increased nutrients, siltation, and turbidity. As the population increased in the Ohio River basin, greater amounts of municipal, industrial, agricultural, and mine effluents were directed into the system. Today, 48.3% of the Ohio River watershed is agricultural, 4.1% is urban, and 1% is mines, while only 36.3% is forested (ORSANCO 1994). The Ohio River has over 600 National Pollutant Discharge and Elimination System (NPDES) permitted discharges to its waters, including those from industry, power generating facilities, and municipalities. One fourth of the total number of NPDES discharges occurs in the upper 160 river kilometers (ORSANCO 1994).

In the early 1800s, there was already interest in altering the channel of the Ohio River to allow for year round navigation (Cramer 1824). While easily navigable in times of high flow, the numerous islands throughout the river resulted in many shoals and sandbars at times of low water, greatly impeding navigation. Interest in removing “ripples” and blowing out rocks from low areas was considerable in order to allow for economic growth to all parts of the river. Also, construction of a “lock-canal” around the Falls of the Ohio at Louisville, Kentucky, was already under consideration (Cramer 1824).

In 1885, the Ohio River underwent the first in a progression of channel modifications that drastically altered the river when the U.S. Army Corps of Engineers (USACE) installed a series of low-lift navigation dams (Pearson and Pearson 1989). Eventually, 50 such "wicket" dams were erected, providing a 3-m-deep navigational channel throughout the year. Starting in 1921, USACE began to replace the low-lift dams with fewer high-lift dams (ORSANCO 1994). Today, there are 18 high-lift dams distributed from Ohio River kilometer 10 (ORKm 10; or 10 km below Pittsburgh) to ORKm 1,478. Below the last high-lift dam are the only two remaining wicket dams, Lock and Dam 52 (L&D 52) and L&D 53 (ORKm 1,549). These two locks and dams are scheduled to be replaced by a high-lift dam currently under construction in the area of Olmsted, Illinois, just downstream of L&D 53. The final 29.6 km of the Ohio River flow freely to the Mississippi River (ORSANCO 1994).

These dams and impoundments have profoundly altered the channel morphology and aquatic habitats of the Ohio River and greatly influenced its fish assemblage (Pearson and Pearson 1989; Lowman 2000). The natural flow of the river was controlled, in effect creating a series of lakes, increasing sedimentation, and altering the temperature regime (Lowman 2000). Fine sediments covered the river's naturally coarse substrate, adversely affecting many lithophilic fish species (Pearson and Pearson 1989). The high lift dams also created physical barriers for many migratory fish, such as American eel *Anguilla rostrata*, greatly limiting their distribution in the Ohio River (Pearson and Krumholz 1984).

Since sections of the Ohio River have been continually impounded for over 100 years, most of the changes observed since 1957 are attributable to changes in water quality (Cavanaugh and Mitsch 1989; Pearson and Pearson 1989). Water pollution affects aquatic life when toxicity results in fish kills, when sublethal effects alter behavior, impede growth, and reduce disease resistance, and when cumulative effects render fish unsafe for consumption (Welcomme 1985). By the middle of the 19th century, Ohio River water quality declined as a result of extensive logging, agriculture, mining, and sewage discharge (Trautman 1981; Taylor 1989). The coal mining and steel industries were major polluters through the 19th and 20th centuries. Acid mine drainage was responsible for pH values of less than 4.0 in the upper 160 km of the Ohio River before 1950 (Pearson and Krumholz 1984). One steel mill effluent with a pH of 3.4 was reported by Williams et al. (1961) to contribute a deep yellow substance to the river that was observable for 100 m downstream. Input of untreated sewage was another major factor in water quality decline. One tributary in the upper part of the river was described as "unpleasant" in appearance and as having an odor "characteristic of sewage-laden streams" (Williams et al. 1961). At least three of 159 species reported from the Ohio River have been extirpated (lake sturgeon *Acipenser fulvescens*, Alabama shad *Alosa alabamae*, and crystal darter *Crystallaria asprella*), primarily as a result of pollution (Pearson and Pearson 1989).

Sporadic attempts to reduce water pollution in the Ohio River valley were being made in the early 1900s (ORSANCO 1962). Significant improvements in Ohio River water quality, especially those related to dissolved oxygen, pH, and total and dissolved metals, have been made since 1950, particularly in the upper 160-km section of the river (Pearson and Krumholz 1984; Reash and Van Hassel 1988; Van Hassel et al. 1988; Cavanaugh and Mitsch 1989). Coal mining and steel operations have been reduced throughout the basin and regulations on discharges have been tightened. Primary sewage treatment was achieved for 90% of the basin's residents by 1960 and secondary treatment facilities were in place by the middle 1970s (Pearson and Krumholz 1984). In the late 1970s, the U.S. Environmental Protection Agency (USEPA) issued the National Municipal Policy that declared all wastewater treatment facilities in the country should have secondary treatment in place by July 1, 1988. While not all facilities accomplished this goal, most in the Ohio River basin met the deadline. These water quality improvements over the last 50 years have improved the quality of the aquatic life of the river.

Rafinesque (1820) conducted the earliest extensive collection of fishes from the Ohio River in 1818 and described over 100 new species of fish, including 26 of 30 species whose type locality is the Ohio River (Pearson and Pearson 1989). Taxonomic revisions reduced the total, but Pearson and Krumholz (1984) concluded that Rafinesque had seen 52 species. Trautman (1981) reported 93 species in 1950 and 103 species in 1980.

The Ohio River Valley Water Sanitation Commission (ORSANCO), an interstate water pollution control agency, was created in 1948 to mitigate water pollution throughout the Ohio River basin. Since the passage of the Clean Water Act (1972), populations of many Ohio River fish species have increased (Emery et al. 1998). Subsequently, a positive shift in fish species composition occurred as pollution tolerant species were replaced by more pollution sensitive species (Cavanaugh and Mitsch 1989). In 1957, ORSANCO, along with cooperating state agencies and academic institutions, conducted the first lockchamber survey of the navigational dams along the Ohio River (ORSANCO 1962). The purpose of this chapter is to document fish assemblage responses to changes in water quality and riverine habitats in the Ohio River over the last 45 years through the analysis of data collected in a consistent manner since 1957.

Methods

Fish Collection Techniques

From 1957 to 2001, 377 fish collections were made using rotenone in lockchambers of 59 different Ohio River navigational dams, including all 18 current high-lift dams and 41 of the 50 original low-lift dams (Table 1; ORSANCO 1992). Most of the collections (90%) were made during the same index period (July–October) as ORSANCO's electrofishing surveys. The lower lock gate was left open for 24 h prior to collection to allow fish to move upstream into the chamber. Field crews using 4–6-m johnboats entered the lockchamber from the downstream side and the lower gate was closed. One crew dispensed rotenone to achieve a concentration of 1 ppm (based on lockchamber size and water depth at time of sampling), making several passes along the chamber.

As they surfaced, fish were netted and placed in containers on the boats. This continued until no more fish surfaced. Fish were identified, sorted into 3-cm size-classes, and weighed. Any small fish not easily identified in the field were preserved in 10% formalin and returned to the laboratory for identification. Most fish identified on site were disposed of according to the regulations of the state in which they were processed. Some specimens were retained as vouchers and are currently stored in museum collections.

Gaps exist in the data used in this analysis because of inconsistencies in the level of identification or reporting of small fishes, particularly species in the families Cyprinidae, Atherinidae, and Fundulidae, and members of the genera *Etheostoma, Percina,* and *Noturus*. At some sampling events, the majority of which occurred in the 1950s and 1960s, small fish either were not identified to species or the data were not added to the database (Pearson and Krumholz 1984). In some cases, minnows were not identified past the family level. Instead, the total number of cyprinids was estimated and batch weighed. Events in which the complete identification of all fish could not be ensured were excluded from analyses of assemblage condition and guild structure, limiting the samples used in these analyses to 157. Also, the numbers for any species considered troublesome to identify were excluded from the percent catch analysis for each individual species. To improve our ability to detect temporal trends, we merged data from the low-lift dams with those from the high lift dams that replaced them.

Water Quality

Temperature, dissolved oxygen, pH, and conductivity were recorded hourly year round from 1961 to 1986 with the use of robot monitoring stations at several Ohio River locations. Since the majority of the samples occurred in September, average values for that month for these four parameters were calculated for these years from five stations (64.6, 489.9, 744.8, 966.6, 1,273.8) to determine water quality trends.

Data Analysis

Fish were assigned to taxonomic, habitat, trophic, and reproductive guilds according to Simon and Emery (1995) and Emery et al. (2002). The modified index of well-being (MIWB) was used to deter-

Table 1.—Location, number, and year of lockchamber sampling events.

Location	River kilometer	Dam type	Number of events	Year range
Emsworth	10.0	high lift	4	1958–1992
Dashields	21.3	high lift	17	1958–1991
Montgomery	51.0	high lift	16	1957–2001
Lock #8	74.7	wicket	1	1958
New Cumberland	87.6	high lift	12	1968–2000
Lock #9	90.3	wicket	1	1958
Lock #10	106.6	wicket	1	1958
Lock #11	123.8	wicket	1	1958
Pike Island	135.6	high lift	20	1967–1999
Lock #12	140.7	wicket	1	1958
Lock #13	154.7	wicket	1	1960
Lock #14	183.5	wicket	4	1958–1959
Hannibal	203.5	high lift	13	1976–2000
Lock #15	207.9	wicket	4	1958–1970
Lock #16	235.9	wicket	1	1958
Willow Island	260.3	high lift	11	1980–1999
Lock #17	269.7	wicket	2	1958–1967
Lock #18	289.6	wicket	1	1958
Lock #19	309.4	wicket	1	1958
Lock #20	326.0	wicket	1	1958
Belleville	328.3	high lift	15	1968–1991
Lock #21	345.5	wicket	1	1958
Lock #22	355.6	wicket	2	1958–1959
Lock #23	372.6	wicket	3	1958–1968
Racine	382.4	high lift	11	1981–2000
R.C. Byrd	449.5	high lift	18	1958–2000
Lock #27	484.6	wicket	1	1958
Lock #28	501.7	wicket	2	1958–1959
Lock #29	515.0	wicket	4	1958–1960
Lock #30	546.4	wicket	4	1957–1959
Greenup	549.0	high lift	12	1967–1999
Lock #31	578.5	wicket	3	1958–1960
Lock #32	616.0	wicket	3	1957–1959
Lock #33	652.2	wicket	2	1958–1959
Lock #34	698.9	wicket	2	1958–1959
Meldahl	702.3	high lift	14	1967–1999
Lock #35	725.9	wicket	3	1957–1959
Lock #36	742.0	wicket	2	1958–1959
Lock #37	778.0	wicket	5	1957–1960
Lock #38	810.3	wicket	2	1958–1959
Markland	855.7	high lift	14	1968–2001
Lock #39	856.0	wicket	4	1957–1959
Mcalpine	976.9	high lift	14	1960–1991
Lock #41	977.3	wicket	28	1957–1959
Lock #43	1,019.5	wicket	7	1957–1970
Lock #44	1,067.8	wicket	3	1957–1959
Lock #45	1,131.8	wicket	3	1957–1959
Cannelton	1,160.3	high lift	15	1968–2001
Lock #46	1,219.3	wicket	5	1957–1974
Newburgh	1,249.5	high lift	9	1968–1991
Lock #47	1,252.1	wicket	4	1957–1959
Lock #48	1,303.5	wicket	3	1957–1959
Lock #49	1,360.5	wicket	4	1957–1960
J.T. Myers	1,362.1	high lift	17	1969–2001

Table 1.—Continued.

Location	River kilometer	Dam type	Number of events	Year range
Lock #50	1,411.6	wicket	6	1957–1970
Lock #51	1,454.0	wicket	3	1957–1959
Smithland	1,478.8	high lift	9	1976–2001
Lock #52	1,511.6	wicket	3	1957–1959
Lock #53	1,549.8	wicket	4	1957–1981

mine changes in assemblage condition in the Ohio River over time. The MIWB, a measure of overall fish assemblage health developed by Gammon (1976) and modified by Ohio EPA to exclude tolerant individuals, sums numbers of individuals and their biomass, as well as Shannon diversity indices based on abundance and weight (Ohio EPA 1987; ORSANCO 1992). We used a linear model form of quantile regression analysis (Terrell et al. 1996; Dunham et al. 2002) to identify temporal trends in species richness, individual species abundance, and guild structure. Water quality data were analyzed by principal components analysis. Spearman correlations were calculated to detect significant relationships among fish assemblage (e.g., MIWB) and water quality variables on the first principal component axis. All analyses were conducted using SAS v. 8.0 (SAS Institute, Cary, North Carolina).

Results

Species Composition

Since 1957, 116 taxa (including 7 hybrids) representing 19 families were identified from the Ohio River lockchamber surveys (Appendix A). The five most common species based on abundance during these surveys were *Dorosoma petenense, D. cepedianum, Ictalurus punctatus, Aplodinotus grunniens, and Notropis atherinoides.* Only 6 of the 116 taxa recorded in this survey are alien to the Ohio River (Appendix A).

Assemblage, Guild, and Species Level Trends

The MIWB increased significantly over time ($r^2 = 0.60$; $p < 0.005$, Figure 2). Similar trends were observed in individual lockchambers from which there were multiple samples. The MIWB scores for events from 1988 to 2001 were significantly ($p < 0.05$) higher than events sampled before 1988 (Figure 3). Secondary treatment of municipal wastewater was established practice in the Ohio River by 1988. At the guild level, several metrics showed significant ($p < 0.05$) temporal trends. Number of native species (Figure 3) and six other metrics showed positive trends with time (Table 2). Percent tolerant individuals (Figure 4), percent alien individuals, percent invertivore individuals, percent simple lithophil individuals, and percent detritivore individuals declined with time (Table 2). The positive correlation of percent individuals as great river species with time likely reflects increasing populations of skipjack herring and blue catfish (Table 2). The biomass of all individuals excluding tolerants also increased significantly ($p < 0.05$) over time (Table 2).

Table 2.—Results of quantile regression analysis of fish assemblage metrics showing significant correlations of metrics with year. NS = not significant.

Metric	R^2	Trend
Number of species	0.31	+
Number of Catostmid spp.	0.34	+
Number of Centrarchid spp.	NS	
Number of Intolerant spp.	0.49	+
Number of Great River spp.	0.31	+
Percent Individuals as Great River spp.	0.20	+
Percent Individuals as Tolerant spp.	0.83	–
Percent Individuals as Nonindigenous spp.	0.43	–
Percent Individuals as Simple Lithophils	0.41	–
Percent Individuals as Detritivores	0.21	–
Percent Individuals as Invertivores	0.56	–
Percent Individuals as Piscivores	0.18	+
Catch Per Unit Effort	NS	
Total Biomass excluding Tolerant Individuals	0.35	+

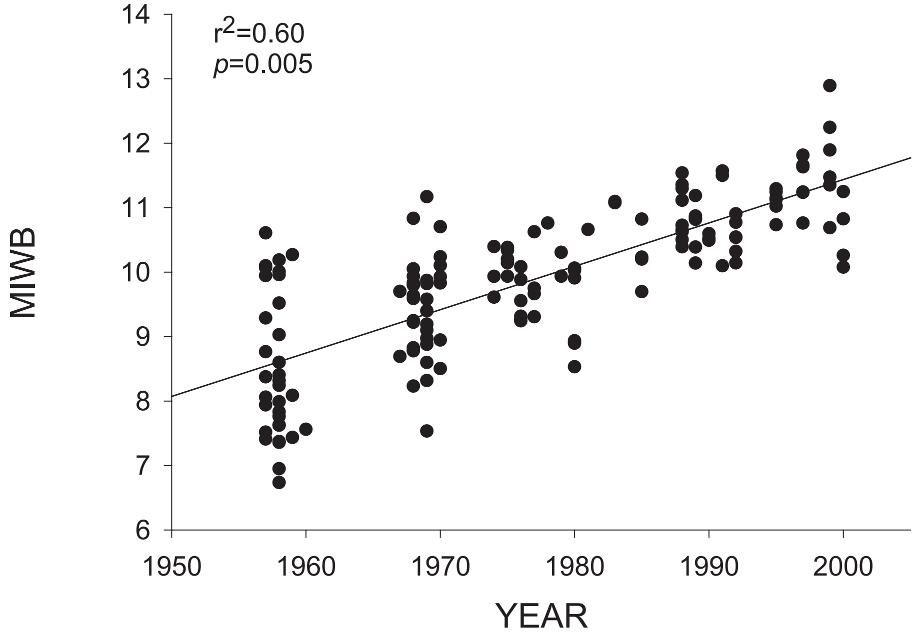

Figure 2.— Plot of modified index of well-being (MIWB) scores from lockchamber data versus year.

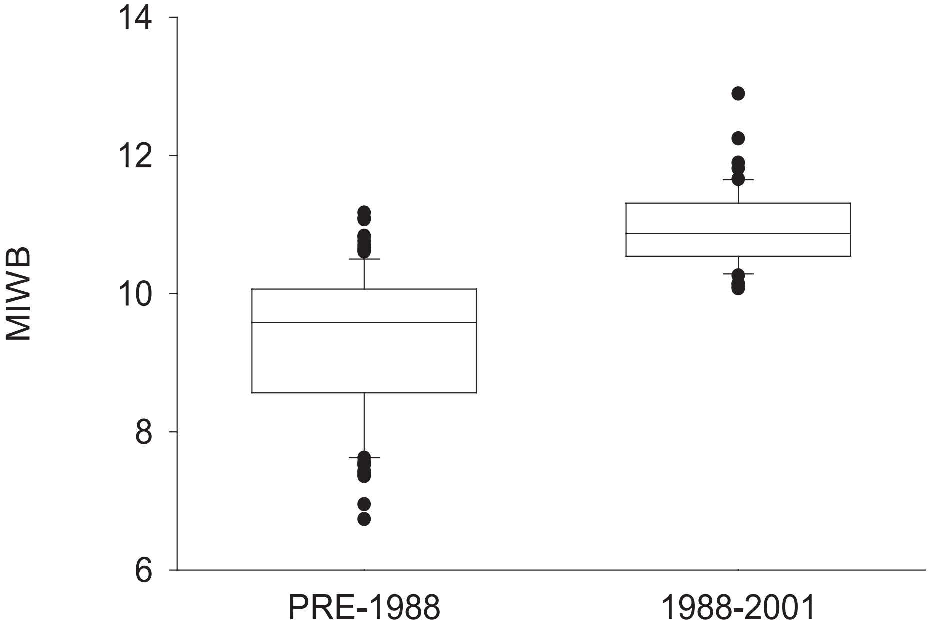

Figure 3.—Modified index of well-being (MIWB) scores before 1988 and after 1988, showing median value, 75th and 25th percentiles (box), 90th and 10th percentiles (whiskers), and outlier values. Secondary treatment of municipal wastewater was established practice in the Ohio River by 1988.

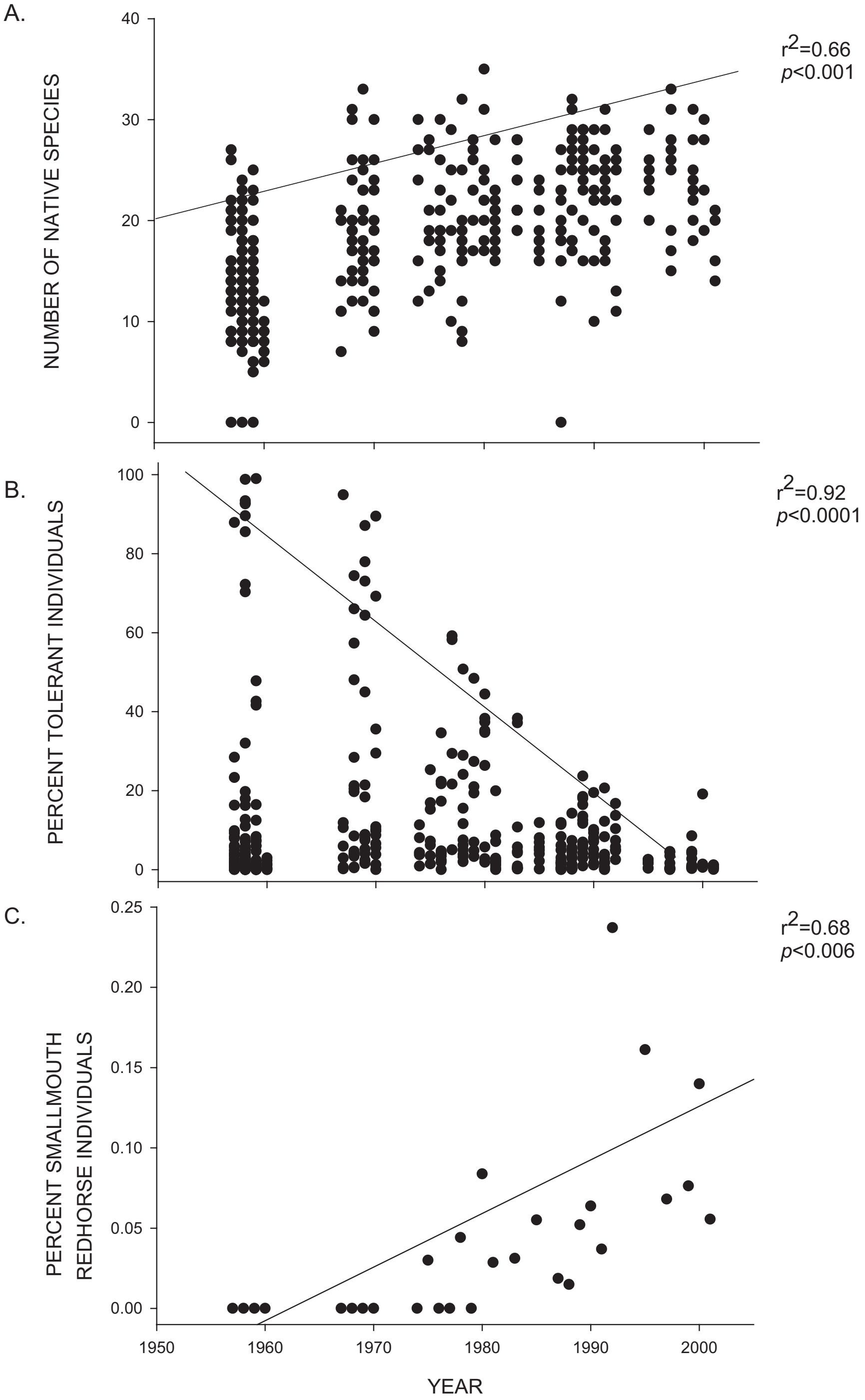

Figure 4.—Quantile regression analyses showing changes in (A) number of species, (B) percent of tolerant individuals, and (C) percent smallmouth redhorse *Moxostoma breviceps* in the Ohio River lockchamber surveys from 1957 to 2001.

Of the 116 taxa, 60 could not be analyzed because taxonomic identification was incomplete or because the range of their abundance was small (0–2). Thirty-five taxa (30%) showed a significant increase with time (e.g., Figure 4), while three pollution-tolerant species (2.6%) declined since 1957, *Carassius auratus*, *Ameiurus melas*, and *A. nebulosus* (Appendix A). Five pollution sensitive species, *Micropterus dolomieu, Moxostoma breviceps, Percina caprodes, Hiodon tergisus,* and *Polyodon spathula* (Appendix A), increased in abundance since 1957; only two tolerant species, *Cyprinus carpio* and *Lepomis cyanellus*, increased; and only one intolerant species, *Hiodon alosoides,* decreased. Sixteen species showed no significant changes over time.

Nonindigenous and Hybrid Species

Only 6 of the 116 species recorded in these surveys are alien to the Ohio River. Twenty-one alewife were collected since 1970. These fish most likely are the result of bait releases and stocking in private lakes (Pearson and Krumholz 1984). Common carp has been a major part of the fish fauna of the Ohio River since the early 1900s (Pearson and Krumholz 1984) and has increased in abundance in lockchamber surveys. Since 1957, the species comprised about 1% of the total catch (ninth most abundant taxon). The first record of bighead carp was reported in 1997 at the J.T. Myers lockchamber. Bighead carp has been stocked in ponds in Arkansas since 1973 to control algae growth (Robison and Buchanan 1988). It was first found in the natural waters of Arkansas in 1986 (Robison and Buchanan 1988), and since then it has been taken with some regularity from the Mississippi in Missouri (Etnier and Starnes 1993). The forty-seven goldfish collected between 1957 and 1989 most likely represent aquarium releases. It has declined in abundance and has not been collected from the lockchambers in 12 years. It has, however, been collected occasionally since 1991 in electrofishing samples conducted by ORSANCO (unpublished data). White catfish was commonly collected at Ohio River lockchambers from 1968 until 1981 above ORKm 450. It has only been recorded once since 1981 at ORKm 1160 in 1990. Striped bass was the 14th most commonly collected species between 1957 and 2001, comprising a little more than 0.3% of the total catch. Striped bass is routinely stocked in the Ohio River and is most likely reproducing (D. Henley, Kentucky Division of Fish and Wildlife Services, personal communication). While several other alien species have been recorded in other Ohio River surveys (ORSANCO unpublished data; Pearson and Krumholz 1984; Burr et al. 1996), these six species represent the only aliens collected in the Ohio River lockchamber surveys. The percent of alien individuals metric has declined significantly with time (Table 2).

Of the seven hybrid taxa, only two occurred in sufficient numbers to be analyzed. Both have increased significantly ($p < 0.05$) since 1957. Saugeye *Sander canadensis* × *S. vitreus* and hybrid striped bass *Morone saxatilis* × *M. chrysops* were caught more frequently in recent lock chamber samples than historically. Karr (1981) indicated that increases in hybrid populations may indicate degraded conditions, these two hybrids are common game fish stocked in the river.

Sensitive Species

Of the 104 native fish species collected in the lockchamber surveys, 39 have special conservation status in the states bordering the Ohio River (Table 2). Twenty-one species represented in Ohio River lockchamber collections are listed as endangered in at least one of the border states, 13 are considered threatened in at least one state, and 11 have a status of special concern in one or more of those states. There is some overlap with these numbers since one species may have different designations in different states. Eleven species listed as special concern, threatened, or endangered in one or more of the Ohio River border states are significantly increasing in abundance based on the percent catch of each species (Appendix A). Conversely, two state-listed species have significantly decreased in abundance in the surveys (Appendix A). Black bullhead is listed as endangered in Pennsylvania. Goldeye, threatened in Pennsylvania and endangered in Ohio, is less common than it was 25 years ago. The number of sensitive species has increased over time (Table 2).

Water Quality Trends

Four water quality parameters (temperature, conductivity, pH, and dissolved oxygen) were highly correlated with the first principal components axis (PCA1), which accounted for 56% of the variability, and showed a significant ($p < 0.05$) increase in water quality over time (Figure 5). Higher dissolved oxygen and higher pH contributed the most to PCA1. A bivariate plot of PCA1 against time for the upper 160 kilometers of the Ohio River, which historically contained the densest concentration of industrial and municipal point sources, showed a significant response in improved water quality with time (Figure 5) and a significant improvement in assemblage condition (MIWB) with improved water quality (Figure 6).

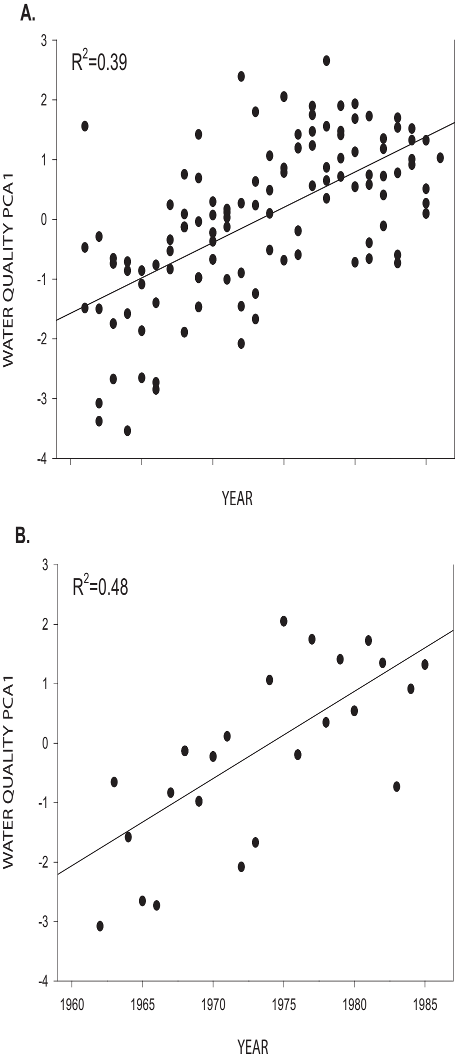

Figure 5.—The first principal component axis of water quality variables (56% of variance explained) for (A) all Ohio River monitoring stations and (B) Ohio River km 0–160 from 1961 through 1986. Positive end of the water quality axis reflects higher dissolved oxygen levels and higher pH.

Discussion

In earlier analyses of this lockchamber data, Pearson and Krumholz (1984) found that nearly all species of fish above ORKm 160 increased in density from 1957 to 1980. They also observed declines in the populations of certain tolerant species, such as bullheads *Ameiurus* spp., throughout the river. Emery et al. (1998) reported replacement of tolerant sucker species such as white sucker by more sensitive species such as redhorses *Moxostoma* spp. in the transitional period from the 1960s to the 1990s. The trends observed in these two analyses indicate that the Ohio River fish assemblage reacted positively to reduced pollution loads. We observed evidence of these same trends in our analysis of the dataset.

Temporal changes in assemblage condition, guild structure, and species structure indicate an improvement in Ohio River lockchamber fish populations (and presumably those of the river) from 1957 to 2001. Increases in MIWB scores, decreased percentages of tolerant individuals, declines in pollution-tolerant species, and recovery of pollution-sensitive species reflect improved water quality as observed by Reash and Van Hassel (1988), Van Hassel et al. (1988), and Cavanaugh and Mitsch (1989). Secondary sewage treatment and reduced toxics discharges are partially responsible for the change in MIWB scores before and after 1988. Increasing species richness, particularly sucker, great river, and intolerant species, indicate general improvement in Ohio River fish assemblages as reported by Pearson and Krumholz (1984) and Emery et al. (1998).

The improvement in the condition of the fish assemblages of the Ohio River is consistent with reports of improvement in its major tributaries and other large floodplain rivers. Gammon (1993) re-

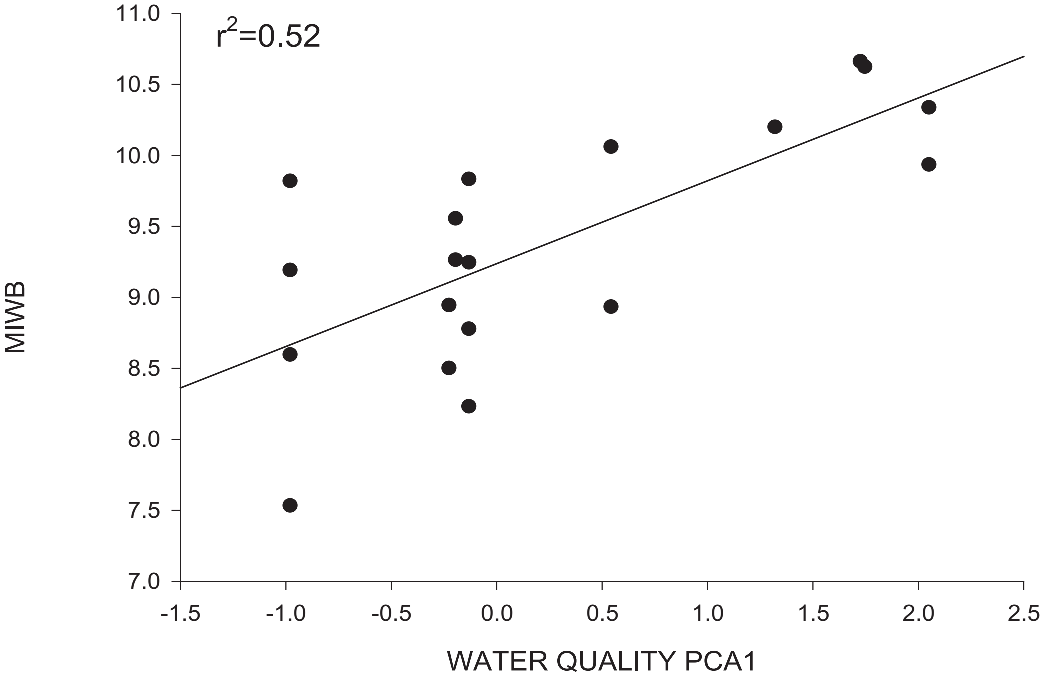

Figure 6—Plot of modified index of well-being (MIWB) versus first principal component axis of water quality variables (56% of variance explained) for Ohio River km 0–160 from 1961 through 1986. Positive end of the water quality axis reflects higher dissolved oxygen levels and higher pH.

ported significant improvements in the condition of the Wabash River fish assemblage (based on his index of well being) from 1973 to 1992 and attributed the improvement to reduced pollution loads, improvement in wastewater treatment, and reductions in nonpoint source pollution from agricultural sources. Yoder and Rankin (1995) attribute comparable improvements in fish and macroinvertebrate assemblages in the Scioto River in Ohio to improvements in wastewater treatment. Hughes and Gammon (1987) cited improvement in Willamette River fish assemblage integrity as a result of improvements in water quality.

However, riverine fish assemblages continue to be threatened by habitat alteration, pollution, hybridization, and invasion by alien species (Warren et al. 2002). Waite and Carpenter (2000) found that impaired fish assemblages were still associated with poor habitat and water quality in Willamette basin steams. In a review of the serial discontinuity concept (SDC) using nine large floodplain rivers, Stanford and Ward (2001) found that downstream recovery of fish assemblages below dams was overwhelmed by water quality degradation. Sparks et al. (1990) cited the disconnected flood plain, sediment loading, and the cumulative effects of point source and diffuse pollution as impediments to the rehabilitation of the Illinois River.

Dams alter a river's most important ecological processes, including impacts to the flow of water, sediments, nutrients, energy, and biota (Ligon et al. 1995; Poff et al. 1997). Alteration of the natural flow regime may further affect fish species with habitat-specific requirements for lotic environments because of altered temperature regimes and barriers to fish migration (Edwards 1978; Winston et al. 1991; De Jalon et al. 1994; Kriz 2000). Nicola et al. (1996) found that migratory species were particularly vulnerable; species of eel, lamprey, sturgeon, and shad were found to be extirpated from wide areas. Fish species diversity was significantly reduced in regulated catchments in the Murray–Darling river system in Australia (Gehrke et al. 1995). In the Vltava River, Czech Republic, dams and pollution regulation were major influences in fish density increases (Kubecka and Vostradovsky 1995). Some of the increases in Ohio River fish species may be attributed to changes in the hydrologic regime from lotic to lentic conditions that favor slackwater species.

The improvement of Ohio River water quality in the last 50 years, particularly in the upper section of the river, has had positive influences on the fish assemblage of the river. These measurable improvements in the fish populations tangibly reflect the gradual abatement of water pollution throughout the Ohio River watershed. While the navigational dams throughout the river will continue to be a major factor affecting fish assemblages, nonpoint source pollution from agricultural and urban runoff, and invasive aquatic species remain greater long-term threats to the health of the Ohio River fish assemblage.

This study shows the value of long-term, consistent monitoring data in detecting trends in fish assemblages and the importance of continuing the lockchamber surveys. The study also indicates that managing for the entire fish assemblage by improving water quality throughout the system may be an important aspect in maintaining a healthy fisheries for recreational purposes.

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Appendix A.—Species collected from Ohio River lockchamber surveys from 1957 to 2001 with guild assignments. *R*-square values are for significant ($p < 0.05$) quantile regressions of species abundance in individual lockchamber surveys vs. year. (NA = Not Analyzed, NS = Not Significant). For GRS, X = Great River Species. For SL, X = Simple Lithophil. For Tol, I = Intolerant, and T = Tolerant. For the five state columns, E = Endangered, T = Threatened, and V = Vulnerable.

Species	Count	R^2	Trend	GRS	Trophic	SL	Tol	NIS	PA	OH	KY	IN	IL
Ohio lamprey *Ichthyomyzon bdellium*	3	NA			piscivore		I		V	E			
silver lamprey *I. unicuspis*	78	0.80	+		piscivore								
Lampetra sp.	33	NA			detritivore								
paddlefish *Polyodon spathula*	319	0.49	+	X	planktivore	X	I			T			
spotted gar *Lepisosteus oculatus*	39	NS			piscivore				E	E			
longnose gar *L. osseus*	699	0.27	+		piscivore				V				
shortnose gar *L. platostomus*	58	0.30	+	X	piscivore					E			
bowfin *Amia calva*	16	NS			piscivore				V				
American eel *Anguilla rostrata*	299	0.57	+	X	piscivore					T			
skipjack herring *Alosa chrysochloris*	46,514	0.49	+	X	piscivore				T				
alewife *A. pseudoharengus*	21	0.44	+		planktivore			X					
gizzard shad *Dorosoma cepedianum*	1,084,684	0.42	+		herbivore								
threadfin shad *D. petenense*	62,843	0.56	+		planktivore								
goldeye *Hiodon alosoides*	411	0.13	–	X	invertivore	X	I		T	E			
mooneye *H. tergisus*	939	0.18	+	X	invertivore	X	I		T				
northern pike *Esox lucius*	1	NA			piscivore								
muskellenge *E. masquinongy*	6	NA			piscivore					V		V	
E. masquinongy x lucius	5	NA			piscivore								
central stoneroller *Campostoma anomalum*	2	NA			herbivore								
red shiner *Cyprinella lutrensis*	1	NA			invertivore								
spotfin shiner *C. spiloptera*	98	NA			omnivore								
steelcolor shiner *C. whipplei*	3	NA			invertivore								
silverjaw minnow *Notropis buccatus*	2	NA			invertivore								
Mississippi silvery minnow *Hybognathus nuchalis*	704	NA		X	detritivore					E			V
bigeye chub *Hybopsis amblops*	29	NA			invertivore	X	I						E

Appendix A.—Continued.

Species	Count	R^2	Trend	GRS	Trophic	SL	Tol	NIS	PA	OH	KY	IN	IL
common shiner *Luxilus cornutus*	225	NA			invertivore								
speckled chub *Macrhybopsis aestivalis*	385	NA		X	invertivore					E			
silver chub *M. storeriana*	11,083	NA		X	invertivore	X			E				
golden shiner *Notemigonus chrysoleucas*	52	NA			omnivore		T						
emerald shiner *Notropis atherinoides*	543,151	NA			planktivore								
river shiner *N. blennius*	765	NA		X	invertivore	X			E				
bigeye shiner *N. boops*	8	NA			invertivore					T			E
ghost shiner *N. buchanani*	3,835	NA		X	invertivore				E				
spottail shiner *N. hudsonius*	98	NA			omnivore						V		
rosyface shiner *N. rubellus*	148	NA			invertivore		I						
sand shiner *N. stramineus*	5,367	NA			invertivore								
mimic shiner *N. volucellus*	62,098	NA			invertivore		I						
channel shiner *N. wickliffi*	11,378	NA		X	invertivore								
pugnose shiner *Opsopoeodus emiliae*	3	NA			detritivore								
suckermouth minnow *Phenacobius mirabilis*	4	NA			invertivore								
bluntnose minnow *Pimephales notatus*	5,028	NA			detritivore		T						
fathead minnow *P. promelas*	38	NA			detritivore		T						
bullhead minnow *P. vigilax*	61	NA			omnivore								
creek chub *Semotilus atromaculatus*	4	NA			invertivore		T						
goldfish *Carassius auratus*	47	0.79	–		detritivore		T	X					
common carp *Cyprinus carpio*	29,594	0.31	+		detritivore		T	X					
C. carpio x Carassius auratus	3	NA			detritivore		T						
bighead carp *Hypophthalmichthys nobilis*	1	NA			omnivore		T	X					
river carpsucker *Carpiodes carpio*	2,794	NS			detritivore								
quillback *C. cyprinus*	971	0.51	+		detritivore								
highfin carpsucker *C. velifer*	136	0.64	+		detritivore								
white sucker *Catostomus commersonii*	152	NS			detritivore	X	T						

Appendix A.—Continued.

Species	Count	R^2	Trend	GRS	Trophic	SL	Tol	NIS	PA	OH	KY	IN	IL
blue sucker *Cycleptus elongatus*	16	NA		X	invertivore	X	I			E		V	
smallmouth buffalo *Ictiobus bubalus*	8,124	0.62	+		detritivore				T				
bigmouth buffalo *I. cyprinellus*	566	0.89	+		detritivore				E				
black buffalo *I. niger*	105	0.92	+		detritivore						V		
spotted sucker *Minytrema melanops*	280	0.19	+		invertivore				T				
silver redhorse *Moxostoma anisurum*	23	0.41	+		invertivore	X							
river redhorse *M. carinatum*	14	NA			invertivore	X	I		V	V		V	T
black redhorse *M. duquesnei*	48	NS			invertivore	X	I						
golden redhorse *M. erythrurum*	129	0.32	+		invertivore	X							
smallmouth redhorse *M. breviceps*	237	0.51	+		invertivore	X	I						
white catfish *Ameiurus catus*	781	NS			omnivore			X					
yellow bullhead *A. natalis*	702	0.16	–		omnivore		T						
black bullhead *A. melas*	6,738	0.37	–		omnivore				E				
brown bullhead *A. nebulosus*	8,156	0.13	–		omnivore		T						
blue catfish *Ictalurus furcatus*	22,170	NS		X	omnivore					E			
channel catfish *I. punctatus*	93,927	NS			omnivore								
mountain madtom *Noturus eleutherus*	6	NA			invertivore				E	E			
slender madtom *N. exilis*	2	NA			invertivore						E		
stonecat *N. flavus*	14	NA			invertivore		I						
tadpole madtom *N. gyrinus*	18	NA			invertivore				E				
brindled madtom *N. miurus*	1	NA			invertivore				T				
freckled madtom *N. nocturnus*	23	NA			invertivore								
flathead catfish *Pylodictis olivaris*	5,730	NS			piscivore								
trout-perch *Percopsis omiscomaycus*	70	NA			invertivore						V		
pirate perch *Aphredoderus sayanus*	78	NA			invertivore					E			
brook silverside *Labidesthes sicculus*	14	NA			invertivore		I		V				
banded killifish *Fundulus diaphanus*	5	NA			invertivore		T						T

Appendix A.—Continued.

Species	Count	R^2	Trend	GRS	Trophic	SL	Tol	NIS	PA	OH	KY	IN	IL
white perch													
Morone americana	1	NA			invertivore								
white bass													
M. chrysops	17,199	0.22	+		piscivore								
yellow bass													
M. mississippiensis	215	0.52	+		invertivore								
striped bass													
M. saxatilis	9,172	NS			piscivore			X					
M. saxatilis x M. chrysops	1,529	0.31	+		piscivore								
rock bass													
Ambloplites rupestris	178	0.63	+		piscivore								
green sunfish													
Lepomis cyanellus	552	0.39	+		invertivore		T						
pumpkinseed													
L. gibbosus	342	NS			invertivore								
L. gibbosus x L. cyanellus	2	NA			invertivore								
warmouth													
L. gulosus	457	NS			invertivore				E				
orangespotted sunfish													
L. humilis	375	NS			invertivore								
bluegill													
L. macrochirus	6,417	0.33	+		invertivore								
L. macrochirus x L. cyanellus	5	NA			invertivore								
L. macrochirus x L. megalotis	10	NA			invertivore								
longear sunfish													
L. megalotis	1,185	0.37	+		invertivore				E				
redear sunfish													
L. microlophus	70	NS			invertivore								
smallmouth bass													
Micropterus dolomieu	324	0.29	+		piscivore		I						
spotted bass													
M. punctulatus	1,735	0.11	+		piscivore								
largemouth bass													
M. salmoides	464	0.34	+		piscivore								
white crappie													
Pomoxis annularis	6,773	0.13	+		piscivore								
black crappie													
P. nigromaculatus	1,970	NS			invertivore								
mud darter													
Etheostoma asprigene	1	NA			invertivore								
greenside darter													
E. blennioides	1	NA			invertivore		I						
rainbow darter													
E. caeruleum	1	NA			invertivore	X							
stripetail darter													
E. kennicotti	13	NA			invertivore								
johnny darter													
E. nigrum	1	NA			invertivore								
banded darter													
E. zonale	1	NA			invertivore		I						
yellow perch													
Perca flavescens	71	NS			invertivore								
logperch													
Percina caprodes	172	0.37	+		invertivore	X	I						

Appendix A.—Continued.

Species	Count	R^2	Trend	GRS	Trophic	SL	Tol	NIS	PA	OH	KY	IN	IL
channel darter													
P. copelandi	3	NA		X	invertivore	X	I		T	T			
blackside darter													
P. maculata	9	NA			invertivore	X							
slenderhead darter													
P. phoxocephala	2	NA			invertivore	X	I						
dusky darter													
P. sciera	14	NA			invertivore	X	I						
river darter													
P. shumardi	10	NA		X	invertivore	X				T			
sauger													
Sander canadensis	5,598	0.38	+		piscivore	X							
S. canadensis x vitreus	280	0.07	+		piscivore								
walleye													
S. vitreus	622	0.27	+		piscivore	X							
freshwater drum													
Aplodinotus grunniens	207,963	NS			invertivore								