THE RELATIONSHIP BETWEEN LONG-TERM MONITORING AND SHORT-TERM PROBLEM ASSESSMENT TECHNIQUES IN MANAGEMENT OF LARGE RIVER-FLOODPLAIN ECOSYSTEMS

Richard E. Sparks, K. Douglas Blodgett, and Thomas V. Lerczak

Illinois Natural History Survey
River Research Laboratory of the Forbes Biological Station
Havana, IL 62644

INTRODUCTION

Large river-floodplain ecosystems have been defined as those where the flood is sufficiently predictable and long lasting that organisms have adapted to utilize the flooded land and expanded floodplain pools and lakes for feeding, spawning, and nurseries (Junk et al. 1989). The habitat complexity and dynamic nature of large floodplain rivers boost biological productivity through a variety of biotic and abiotic processes (the "floodpulse advantage" described by Bayley 1991), but also challenge biologists who design sampling programs to detect trends and sort out natural from human-induced changes in fish and wildlife populations. The Illinois River is a good test for survey design and for problem identification and assessment techniques because it is a large, complex floodplain river and has experienced virtually every impact associated with human development of rivers and their basins, with the exception of acid mine drainage and high dams (Sparks 1992). This paper describes a long-term fish population survey on the Illinois River and how the results provided preliminary insights into problems that subsequently were investigated using ancillary sampling and toxicity evaluations.

DESIGN OF A LONG-TERM FISH POPULATION SURVEY

The study area

Human influences on the Illinois River are separated in space: the upstream reaches are strongly affected by the Chicago urban area and the downstream reaches by drainage from the corn belt that runs across the middle of the state (Figure 1). Virtually any major constituent of urban or industrial waste increases upstream toward Chicago (e.g., total ammonia, Figure 2), whereas suspended sediment concentrations (which reflect soil erosion associated with agriculture) increase downstream (Figure 3). The fish population survey was designed to cover the entire length of the river (in fact, more than the length of the river, as explained below), to take advantage of the physical separation of urban and agricultural impacts in interpreting upstream-downstream changes in fish populations.

Urban impact on the river was drastically increased in 1900, when the Chicago Sanitary and Ship Canal was opened to carry city wastes away from Lake Michigan and down the Des Plaines River to the Illinois River (Figure 1). The flow of the Chicago River had been reversed as early as 1871 for the same purpose, but the volume of waste was smaller and the impacts more localized then because of the smaller conveyance capacity of the older channels (Sparks 1977). Today the interconnected channels and rivers comprise a 2.7-m-deep (9 feet) commercial navigation channel, the Illinois Waterway, that links Lake Michigan to the Mississippi River. Twenty-four of the electrofishing stations are in
the Illinois River proper, two are in the Des Plaines River, and one is in the Mississippi River, just downstream of the mouth of the Illinois, and serves as a reference station that historically has been less perturbed by pollution than the stations in the Illinois River. Locations in the figures and text are given in Illinois Waterway miles, rather than kilometers, because mileages are used in the chartbooks furnished by the U.S. Army Corps of Engineers and are posted along the waterway starting with mile 0.0 at the Mississippi-Illinois confluence and extending upstream to mile 327 where the Chicago River joins Lake Michigan at the Thomas J. O'Brien Lock.

The waterway is divided into 8 reaches defined by low navigation dams that range in height from 3 m (10 ft) to 12 m (38 ft); only the lower six reaches are included in the electrofishing survey. The Corps of Engineers names the dams according to a town or other nearby geographical feature and refers to the reaches between dams as navigation pools, with each pool sharing the name of the downstream dam that forms it; e.g., the Peoria Dam is at Peoria, Illinois and backs up water in the Peoria Pool. The three upstream pools (Dresden, Marseilles, and Starved Rock) are in a relatively narrow 0.8 km-wide (0.5 mile) bedrock valley, that contrasts greatly with the 3-km to 12-km-wide (1.8 to 7.2 miles) floodplain and formerly extensive backwaters of the three pools downstream (Peoria, La Grange, and Alton). Although half of the former floodplain in the downstream pools has been drained, primarily for agriculture, 81,000 ha (200,000 acres) remain in a mosaic of state and federal public lands and private waterfowl hunting clubs that are concentrated in the Peoria and LaGrange pools (Bellrose et al. 1983; Mills, Starrett and Bellrose 1966).

Sampling gear

An ambitious long-term fish sampling program on the Illinois River was initiated by W.C. Starrett in 1957 and originally included use of several types of active and passive sampling gear, each adapted to certain types of big-river habitat. Over the last 35 years it was not possible to continue the same level of effort and also follow up on problems the survey had identified, so sampling with a boat-mounted electrofishing rig became the standard technique, for logistical and technical reasons. With the electrofishing boat, two people can sample 27 sites (usually electrofishing for an hour at each site) along a 280-mile (451-km) reach of the Illinois Waterway in the relatively brief span of 15 work days in the field, excluding time required for preparation of equipment and downtime because of equipment failure or bad weather.

Although the efficiency of any sampling gear varies according to the behavior and size of the fish, the skills of the operator, and characteristics of the habitat, electrofishing is capable of capturing a wide range of sizes and species. The size range is limited on the small end of the scale primarily by the mesh size of the dip net and the ability of the dipper to see the fish and on the other end by the ability of larger fish to detect and avoid the electric field before they are stunned (Bayley and Dowling 1990; Austen 1992). Electrofishing is virtually the only nondestructive (to fish and habitat) technique that can extract fish from the brush piles, log jams, and root masses along undercut banks that provide most of the natural habitat structure for fish in the Illinois River.
Measurements

Most of the fish are identified, weighed, measured for total length, and checked for external abnormalities in the field, then returned alive to the waterway. Fish that may be difficult to identify (e.g., some hybrids) are preserved and examined later in the laboratory. The type and location of abnormalities on the fish are recorded, and include such things as sores or lumps on the body, eroded fins, external parasites, and skeletal deformities such as spinal curvature or a bulging condition of the operculum known to commercial fishermen as "knothead".

Sampling limitations

Electrofishing does have limitations that must be considered in designing the sampling program and interpreting the results. A key factor is that the stunned fish must be seen by the person with the dip net to be caught, hence we set the electric field to a relatively shallow maximum depth of 1-1.5 m in the turbid Illinois Waterway and fish along shorelines. Bottom-dwelling fishes are underrepresented in the catch, and species that occupy deep portions of the main channel, such as sturgeon, are taken rarely, if at all. Because of these and other sampling limitations our electrofishing does not quantify the population size in numbers or biomass per unit area or volume of habitat, but does indicate relative abundance (catch per 60 minutes of sampling effort, in our case--some investigators use catch per unit length of shoreline). As long as the capture efficiency for each species is the same year-to-year and place-to-place, fluctuations in catch will reflect real differences in the populations, although the exact relationship can only be determined by gear calibration experiments as suggested by Larimore (1961), Bayley and Dowling (1990), and Austen (1992). Consistent capture efficiency requires using the same techniques (same equipment, same boat speed, etc.) under consistent environmental conditions, a point that is discussed next.

Temporal considerations

An important consideration in a large floodplain river is the time of sampling in relation to annual floods and temperature cycles. Fish disperse in the expanded aquatic habitat when water levels are high thereby lowering capture efficiency. They also change their distribution seasonally, e.g., moving between spring spawning areas and wintering areas. We sample between the last week of August and the first week of October because the river is usually in a stable low-flow condition, with constant water levels maintained by the navigation dams, and the fish have not moved into wintering areas. Also, by fall the young fish produced during the spring flood have grown large enough to be vulnerable to capture and the low water levels concentrate the fish in the permanent channels that we sample. By capturing young-of-the-year, we gain information about the reproductive success and early growth of fish in the year of sampling. If we sampled earlier, we might miss the young fish and have to wait a year before they were large enough to show up in our samples; hence, we might not detect a reproductive failure until more than a year after the event. We do not sample during floods, even if they occur during our seasonal sampling "window", because it would be impossible to separate the effects of high water in reducing our capture efficiency from a real decline in the population.
Habitat stratification

The aquatic habitats available to fish during the stable, low-flow period can be broadly divided into permanent backwaters, with lentic conditions, and permanent channels with flowing water. Although each of these can be further subdivided (Figure 4), we here consider only the shallow channel borders that we actually sample. We cannot adequately sample all habitats along the length of the entire waterway because of manpower limitations, and the fish in the channels are most consistently exposed to the broadscale water quality effects that we hope to detect, whereas fish in backwaters are subject to strong local effects once the floodwaters recede and the hydraulic connections among backwaters and channels are diminished or severed. Local effects include such things as heavy predation on fish by herons from an adjacent rookery, development of anoxic conditions, or sediment resuspension by wind-driven waves in backwaters with a long wind fetch.

Channel habitats include the main navigation channel and shallower side channels, up to 17 km (10 miles) long, around islands. Our sampling generally is conducted along the shallow borders and cut banks of the main channel and major side channels. Where the length of shoreline available for sampling exceeds what can be covered in 60 minutes, a segment is chosen within the site that includes natural habitat structure such as a brush pile, or man-made structures such as boat docks. During the 35 years of the electrofishing survey, three of the side channels have shortened because of erosion of islands, to the point where the sampling time had to be reduced to 30 minutes, to avoid going back over the same area or going outside the side channel.

RESULTS AND DISCUSSION

We use the example of the electrofishing survey of the Illinois Waterway to suggest an approach to three fundamental questions that biomonitoring is expected to answer: Have conditions improved? What problems remain? What causes the problems? We briefly describe some of the upstream-downstream and year-to-year trends in the fish populations of the Illinois Waterway and how the data provided preliminary insights into factors responsible for the trends—factors that were later confirmed by short-term, problem-directed studies. The presentation is organized according to the types of information provided by the electrofishing survey: (1) relative abundance of fishes, (2) fish health, as determined by body condition (body length/body depth ratio or weight at a given length), and (3) fish health, as determined by incidence of abnormalities.

Relative abundance

The relative abundance of fish species in the Illinois Waterway reflects both agricultural and urban impacts. The occurrence of white crappie (Pomoxis annularis) primarily in the lower Illinois River probably reflects the known tolerance of this species for turbid water, or perhaps some competitive advantage in turbid water in relation to its congener, the black crappie (Pomoxis nigromaculatus), which is known to prefer clearer water (Figure 5; Smith 1979). Species that spawn in aquatic vegetation, such as black buffalo (Ictiobus niger) and yellow bass (Morone mississippiensis) are now rare in the lower river where submerged aquatic vegetation has been largely eliminated by reduced light penetration, watery sediments that do not provide good roothold,
and frequent resuspension of sediments by boat- or wind-driven waves (Sparks et al. 1990).

In the upstream pools closest to Chicago, the electrofishing catches were dominated by the introduced common carp, goldfish, and hybrids of the two, from the 1960s until the 1980s (Sparks 1977; Sparks and Starrett 1975). In contrast, catches from downstream pools contained a variety of native species, and could be characterized as largemouth bass-bluegill communities. Brightly-colored goldfish were common in the catch from Dresden Pool, apparently because there were no native piscivores to consume them. The situation changed in the 1980s: native species, including bluegill, largemouth bass, smallmouth bass, and sauger returned to the upstream pools, and brightly colored goldfish were replaced by drab ones. After becoming uncommon in the 1950s, sauger have returned (Figure 6) and supported a nationally-ranked annual fishing tournament at Marseilles for the past four years. Today, the Illinois River provides 2 million angling days per year, valued at $40 million annually, and hunters spend an additional $44 million per year (Conlin 1991).

The Peoria Convention and Visitors Bureau is hoping to attract the BASSMASTER Classic in August 1993 and again in 1994, which the Bureau estimates will boost the regional economy by $14 million.

Two lines of evidence support the contention that this favorable change is largely attributable to improvements in water quality. First, the drought of 1988-1989 did not cause as severe a depression in populations of native game fishes (e.g., largemouth bass, Figure 7) as the drought in the mid-1960s. Although both droughts probably reduced the production of game fish because of the reduction or absence of the floodpulse, low oxygen levels and other pollution-related stresses were more severe in the 1960s and 1970s and probably reduced the survival of even adult fish (Sparks and Starrett 1975).

The other line of evidence comes from short-term field studies on the relationship between water quality and fish communities in the Illinois River and in the Du Page River, a northern tributary of the Illinois in the Chicago area (Lubinski and Sparks 1981; Brigham and Hey 1981). In these studies, chemical concentration units were converted to toxicity units and then summed to provide an estimate of total stress on the fish, taking into account the effects of factors that modify chemical equilibria or the sensitivity of the fish (temperature, pH, dissolved oxygen, calcium concentration). Stress values greater than 1.0 were associated with fishless reaches in Du Page River, and threshold values of 0.2-0.4 were associated with a shift from bass-bluegill communities to carp-goldfish communities in both the Illinois River and Du Page River. Application of the stress index to water quality data from the Illinois River indicates that un-ionized ammonia from Chicago remains a major contributor to toxicity in the upper waterway, but that the stress levels in the Chicago area and in the rest of the waterway have been substantially reduced since 1975 (Figure 8). A by-product of the stress analysis is the indication that present Illinois Pollution Control standards are not protective of fish, particularly small ones at winter temperatures, so more stringent standards appear to be warranted (Figure 9).

**Condition factor**

Two condition factors have been applied during the electrofishing survey. The ratio of body depth to total length is an index of the relative plumpness of commercially valuable species, such as the common carp. High values indicate a relatively thin fish, whereas low values indicate a more marketable fish. The relative weight index, \( W_r \), compares the weight of a fish to an ideal
weight for a fish of that same length and species (Figures 10 and 11). The ideal weight (which has a value of 1.0) is based on the top quartile of length-specific weights from bodies of water in the same geographic region where fish are known to grow well (Murphy, Brown and Springer 1990).

There is a remarkable contrast between $W_0$ for bluegill and common carp (Figures 12 and 13). The bluegill has not only recolonized the upper Illinois Waterway in the 1990s, but also appears to be growing well, with $W_0$ values consistently greater than 1.0 (Figure 12). The bluegill $W_0$ values have increased dramatically in all the navigation pools but one since 1963 (Figure 12). Conversely, $W_0$ for carp has declined in every pool since 1963, and the 1991 values are substantially below 1.0 (Figure 13). The difference is probably explained by differences in the food supply. The common carp is a rooting type of bottom feeder which can consume detritus, but seems to do better on benthic macroinvertebrates; in the Illinois Waterway, at least, there is a significant correlation between the body depth/length ratio and the availability of benthic macroinvertebrates (Figure 14). Populations of benthic macroinvertebrates have been low in the Illinois Waterway since a major dieoff in 1958 and have not recolonized to their former numbers (Sparks 1984). Recent studies by the Illinois Natural History Survey indicate that pore water in the sediments of the Illinois Waterway contain levels of ammonia that are toxic to fingernail clams, Musculium transversum, which once were major food items for bottom-feeding fish and diving ducks (Sparks, Blodgett and Dillon 1991). In contrast to carp, bluegill feed by picking at insects that may be on the surface, submerged substrates, or on the bottom sediments, and these invertebrate clingers and sprawlers (sensu Cummins and Merritt 1984) have benefited from improved water quality, as indicated by greater numbers of relatively pollution-intolerant forms appearing on artificial substrates suspended in the water column (Illinois Environmental Protection Agency 1990). The difference between the condition of bluegill and carp thus appears to be related ultimately to the difference in the quality of water and sediments, which in turn affects the food organisms of the fish.

Incidence of abnormalities

In the 1960s, virtually all the fish collected in the Dresden Pool close to Chicago had abnormalities of various kinds and although the incidence of abnormalities declined downstream, 20% of the fish were abnormal as far downstream as 290 km (180 miles) from the city (Figure 15). Virtually all the carp in Dresden Pool had the knothead condition described above and a few fish in every collection had lumps or spinal deformities such as curved backs and upturned tails. A study of similar abnormalities in the fishes of the Fox River, a tributary of the Illinois, indicated that tumors and precancerous lesions were associated with the presence of carcinogens in the water (Brown et al. 1973). By 1991 only 10% of the fish in the Dresden Pool showed external abnormalities, mostly sores and eroded fins, and the incidence was even lower in the downstream pools. Few carp now have knothead. Most of the eroded fins occur in bottom-dwelling fish, and the ventral barbels and fins of these fish are most likely to be eroded or in the process of regenerating after being eroded, indicating that the condition may be caused, or at least aggravated, by contact with the sediment. It would be worthwhile to determine whether the sediments contain biological or chemical agents that induce the fin erosion--one more example of a preliminary insight and line of inquiry suggested by the results of the electrofishing survey.
SUMMARY

In its relatively brief course of 300 miles (480 km), the Illinois Waterway is subject to major urban and agricultural impacts that occur commonly on many rivers throughout the United States. The waterway is exceptional, however, in that the effects of these disturbances on fish populations have been documented by an annual electrofishing survey that is probably unique in duration (35 years) and consistency of sampling technique. The duration of the record makes it possible to detect trends that would otherwise be obscured by annual variations and to sort out human-induced changes from natural environmental fluctuations, such as droughts and floods. Despite the natural complexity of the large floodplain river system and the variety of human disturbances to which it has been subjected, the relatively simple electrofishing survey has provided semi-quantitative assessments of fish communities and preliminary insights into the factors that influence them. Some of these trends subsequently were linked to causes through ancillary sampling (e.g., of macroinvertebrates which fish feed upon) and toxicity identification and evaluation procedures.
REFERENCES

BIBLIOGRAPHY ON ELECTROFISHING:


A bibliography on general techniques and uses of electrofishing and effects of electrofishing on fish and invertebrates; also lists manufacturers and distributors of electrofishing equipment.

GRADIENT ANALYSIS AND ORDINATION TECHNIQUES:


EFFICIENCY OF ELECTROFISHING:


FLOODPULSE CONCEPT:


ILLINOIS RIVER:


RESTORATION:


STRESS INDICES FOR FISH:


TUMORS IN FISH:


POINTS OF CONTACT

Temple, Alan J. (Electrofishing short courses and information) Fisheries Academy National Fisheries Center - Leetown Route 3, Box 49 Kearneysville, WV 25430 (304) 725-8463

Registry of Tumors in Lower Animals (Tumors in fish) National Museum of Natural History Room W216-A Smithsonian Institution Washington, D.C. 20560
Figure Legends

Figure 1. Location of the electrofishing stations. The Illinois River is joined to Lake Michigan via the Des Plaines River and the canal system in the Chicago area. The entire system, from Lake Michigan to the confluence with the Mississippi River, is known as the Illinois Waterway.

Figure 2. Total ammonia concentrations increase in the upstream direction, toward Chicago. Between 1975 and 1990 the concentrations have substantially declined. IEPA = Illinois Environmental Protection Agency. USGS = U.S. Geological Survey. MWRDGC = Metropolitan Water Reclamation District of Greater Chicago.

Figure 3. Secchi disk readings (a measure of water clarity) decline in the downstream direction, where tributaries introduce erosion silt from agricultural areas. Submersed aquatic plants are virtually absent from the river downstream of mile 220, at least partly because of the reduced light penetration.

Figure 4. Types of aquatic habitat available in the Illinois River. The Illinois River electrofishing survey is conducted in the shallow borders of the main channels and side channels.

Figure 5. Pounds of black crappie and white crappie collected per hour in the Illinois River in 1991. The black crappie prefers moderately clear water, whereas the white crappie tolerates turbid water and occurs primarily in the turbid lower river.

Figure 6. Number of sauger collected in the Illinois River, 1957-1991.

Figure 7. Pounds of largemouth bass collected per hour in the Illinois River, 1959-1991. Bass returned to the upper river (Marseilles and Starved Rock pools) starting in 1973. The catch rate of largemouth bass did not decline as much during the 1988-1989 drought as during the drought of the mid-1960s, indicating improvement in waste treatment and water quality in the interim.

Figure 8. Decline in ammonia toxicity between 1975 and 1990, as measured in bluegill toxicity units (BGTUs). A BGTU of 1.0 is the lethal threshold, 0.2 is the threshold for degradation of the fish community, and values below 0.2 allow populations of native fishes to sustain themselves (see text).

Figure 9. Toxicity, in bluegill toxicity units (BGTUs), of hypothetical water samples that meet water quality standards. A BGTU of 1.0 is the lethal threshold, 0.2 is the threshold for degradation of the fish community, and values below 0.2 allow populations of native fishes to sustain themselves (see text).

Figure 10. Calculation of relative weight, \( W_r \).

Figure 11. Examples of standard weight-length relationships for calculating \( W_r \) for bluegill and carp. \( W_s \) = standard weight. \( L \) = total length.
Figure 12.  $W_r$ for bluegill in the Illinois River in 1963, 1975, and 1991.  In 1963 and 1975 no bluegill longer than 80 mm were caught in the upstream part of the Illinois Waterway (Marseilles and Dresden pools), near Chicago.  $W_r$ of bluegill has increased in recent years, exceeding the index value of 1.0 throughout the river.

Figure 13.  $W_r$ for carp in the Illinois River in 1963, 1975, and 1991.  In contrast to bluegill, $W_r$ of carp has declined in recent years.

Figure 14.  Relationship between carp condition (body depth/length ratio) and food supply (benthos) in 1975.  High values for the condition index indicate a thin fish of little market value in the commercial fishery.

Figure 15.  Incidence of fish with externally-visible abnormalities in the Illinois River in 1963, 1975, and 1991.  Numbers above each bar indicate the total number of fish caught.
IPCB standards (general use):
- total ammonia N = 15.0 mg/l
- un-ionized ammonia = 0.04 mg/l

- 1975  No. of stations = 12  (IEPA)
- 1990  No. of stations = 16  (USGS, MWRDGC)
1991

Black Crappie

White Crappie

Biomass (lb) Per Hour

Illinois Waterway Pool

Alton
Lagrange
Peoria
Starved Rock
Marseilles
Dresden Island
Total number of Sauger collected by INHS during annual surveys of the Illinois Waterway (NF indicates years Not Fished)
Mean Flow (21,900 Thousand Cubic Feet per Second) in MSE

Pounds of Largemouth Bass per Hour

NF = Not Fished
NC = Not Calculated
<table>
<thead>
<tr>
<th>Bluegill Size class (mm)</th>
<th>BGTU 4°C</th>
<th>BGTU 32°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>22.7</td>
<td>7.2</td>
</tr>
<tr>
<td>100</td>
<td>8.2</td>
<td>2.6</td>
</tr>
<tr>
<td>150</td>
<td>0.31</td>
<td>0.10</td>
</tr>
</tbody>
</table>

IPCB standards:
- total ammonia = 15mg/l
- DO = 5 mg/l
- pH = 9.0
The Relative Weight Index \( (W_r) \)

\[
W_r = \frac{W}{W_S} \times 100
\]

where,

\( W = \) individual fish weight

\( W_S = \) length-specific standard weight
Examples of $W_S$:

Bluegill

$$\log W_S = 3.316 \log(L) - 5.374 \quad \text{for } L \geq 80 \text{ mm}$$

Carp

$$\log W_S = 2.859 \log(L) - 4.418 \quad \text{for } L \geq 280 \text{ mm}$$

Fisheries 16:30-38.
Mean relative weight for bluegill (length ≥ 80 mm).

\[
\overline{Wr} (1963) = 0.914 \quad \overline{Wr} (1991) = 1.08 \\
\overline{Wr} (1975) = 0.984
\]

Mississippi River
Alton
LaGrange
Peoria
Starved Rock
Marseilles
Dresden

Illinois Waterway Pool
Mean relative weight for carp (length ≥ 280 mm).

Wr (1963) = 0.877  Wr (1991) = 0.795
Wr (1975) = 0.781
RELATIONSHIP BETWEEN CONDITION FACTOR OF CARP AND BOTTOM FAUNA IN THE ILLINOIS RIVER IN 1975

CORRELATION COEFFICIENT = -0.747
SIGNIFICANCE LEVEL = 0.999

Carp Condition Factor (Standard Length/Body Depth)

Bottom Fauna Kilograms/Hectare