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LONG-TERM ECOLOGICAL RESEARCH ON ILLINOIS RIVERS

by
N.G. Bhowmik,[1] J.R. Adams,[2] R.V. Anderson,[3] R.A. Cahill,[4]
M. Demissie,[5] D.L. Gross,[6] J.E. King,[7] K.S. Lubinski,[8]
P.G. Risser,[9] R.E. Sparks,[10] and W.W. Wendland[11]

ABSTRACT

This paper presents the concepts and goals of the Long-Term Ecological Research (LTER) at the Illinois River sites. The "Illinois Rivers" or "large rivers" sites are described with regard to their size, diversity, and dynamic ecosystems. The large river LTER project includes four research components: 1) succession and perturbation, 2) water and sediment fluxes, 3) biotic system structure, and 4) ecosystem function. The research focus of the first several years is given for each component. Significant early findings are also described. These results are being used to develop an integrated model including a hydrologic-hydraulic component and a biological community component. The high productivity of these large rivers is described in terms of plankton, macrophytes, and benthic organisms.

[1]Principal Scientist and Assistant Head, Surface Water Section, Illinois State Water Survey, Urbana-Champaign 61820
[2]Professional Scientist, Surface Water Section, Illinois State Water Survey, Urbana-Champaign 61820
[3]Assistant Professor, Division of Biological Sciences, Western Illinois University, Macomb 61455
[4]Chemist, Illinois State Geological Survey, Urbana-Champaign 61820
[5]Professional Scientist, Surface Water Section, Illinois State Water Survey, Urbana-Champaign 61820
[6]Geologist and Head, Environmental Studies and Assessment Unit, Illinois State Geological Survey, Urbana-Champaign 61820
[7]Head of Scientific Sections, Illinois State Museum, Springfield 62706
[8]Assistant Aquatic Biologist, Illinois Natural History Survey, Grafton 62037
[9]Chief, Illinois Natural History Survey, Urbana-Champaign 61820
[10]Aquatic Biologist, Illinois Natural History Survey, River Research Lab, Havana, and Director of Illinois Rivers LTER Project 62644
[11]Principal Scientist, Illinois State Water Survey, Urbana-Champaign 61820

INTRODUCTION

The Illinois Natural History Survey, Illinois State Water Survey, and Illinois State Geological Survey, located on the campus of the University of Illinois, Urbana-Champaign, and the Illinois State Museum and Western Illinois University are in the third year of a long-term multidisciplinary research project on the ecology of the Mississippi and Illinois Rivers. This is one of the eleven sites around the country where more than 100 scientists and researchers are conducting research on various aspects and components of the natural environment.

The fundamentals of this research are outlined in the program brochure by Halfpenny and Ingraham (1984). Long-Term Ecological Research (LTER) is a program supported by the National Science Foundation's Division of Biotic Systems and Resources. The program was developed during the period from 1976 to 1979 with first open competition for support announced in 1979. LTER acknowledges that:

1) There are ecological phenomena that occur on time scales of decades or centuries, periods of time not normally investigated with research support from the National Science Foundation or other sponsors.

2) Many ecological experiments are performed without sufficient knowledge of the year-to-year variability in the system. Interpretation is, therefore, difficult. This is especially true when the system in which the experiment is performed is not at equilibrium.

3) Long-term trends in natural ecosystems were not being systematically monitored. Unidirectional changes that were observed could not be distinguished from cyclic changes on long time scales.

4) A coordinated network of sites was not available to facilitate comparative experiments. Furthermore, data management was not being coordinated between research sites. Therefore, comparative analyses could not be performed and theoretical constructs could not be conveniently tested.

5) Natural ecosystems were being converted to uses incompatible with ecological research.

6) Advances in ecological research have often treated phenomena at higher or lower levels of organization as constant or insignificant. This problem can be alleviated by performing intensive investigations at single sites, leading to an accumulation of overlapping information. Through time, site specific research will generate increasingly valuable data sets that will reveal pattern and control at several levels of ecosystem organization.

Initial convergence of LTER effort was encouraged by requiring that sites address research efforts in five core areas: 1) pattern and control of primary production; 2) spatial and temporal distribution of populations selected to represent trophic structure; 3) pattern and control of organic matter accumulation in surface layers and sediments; 4) patterns of inorganic inputs and movements of nutrients through soils, groundwater, and surface waters; and 5) patterns and frequency of disturbance to the research site.

The institutions supporting the LTER sites are committed to encouragement of collaborative research by scientists at other institutions. LTER sites are to be considered regional or national research facilities. Scientists who wish to use the sites can contact the project directors directly. Every LTER program has an outside review team which meets at least once a year at the site to evaluate the program and recommend improvements.

Figure 1 shows the locations of the eleven LTER sites. The following list gives the names of the research sites, the general physical features of the sites, and the princpal research organizations involved in the research projects.

H.J. Andrews (Coniferous forest), Oregon State University and U.S. Forest Service.

Cedar Creek Natural History Area (Oak savanna), University of Minnesota.

Central Plains Experimental Range (Grassland), Colorado State University.

Coweeta Hydrological Laboratory (Deciduous forest), University of Georgia and U.S. Forest Service.

Illinois Rivers (Temperate rivers), Illinois State Natural History, Water, and Geological Surveys; State Museum; and Western Illinois University.

Jornada (Desert), New Mexico State University.

Konza Prairie Research Natural Area (Tallgrass prairie), Kansas State University.

Niwot Ridge (Alpine tundra), University of Colorado.

North Inlet (Coastal marine), University of South Carolina.

Northern Lakes (Northern temperate lakes). University of Wisconsin.

Okefenokee National Wildlife Refuge (Freshwater wetland), University of Georgia and U.S. Fish and Wildlife Service.

Illinois Rivers LTER Site

The Illinois Rivers LTER site draws contributions and participation from scientists and engineers from five separate institutions. The major research topics are: succession and perturbation; water, sediment and nutrient budgets in habitat compartments, including mathematical modeling; relationship between community structure and geomorphic structure and hydrologic regime; and sources, sinks, distribution, and processing of organic matter. The main communities within this temperate freshwater environment are: freshwater marsh; northern floodplain forest; off-shore and mud-bottom benthos; submergent, emergent, and floating aquatic plant beds; phytoplankton and zooplankton; and the firm substrate community in swift current.

The Illinois Rivers LTER site encompasses three different locations on two major rivers: Pool 19 and Pool 26 on the Mississippi River, and Peoria Lake on the Illinois River (figure 2).

This research project was initiated in 1981, and data collection began in 1982. The broad objectives of the long-term research are: 1) to explain the basis and controls of productivity in large floodplain rivers, 2) to determine temporal and spatial patterns of nutrient inputs, losses, and utilization, 3) to examine effects of natural and man-made perturbations (including droughts, floods, navigation dams, barge tows, and contaminants) on key species and processes, and 4) to define relationships between community structures and the hydrologic regime and geomorphic structure. Specific research approaches include: 1) reconstruction of historical and pre-historical disturbances using cores from sediments and trees, 2) sampling and modeling of populations of key producers and consumers, 3) sampling and modeling of water, sediment, and carbon flows in habitat compartments, and 4) analyses of successional patterns in both natural floodplain lakes and navigation pools.

The project initially was subdivided into four components: 1) succession and perturbation in the Illinois and Upper Mississippi Rivers, 2) hydrological environment, water, sediment and mathematical modeling, 3) ecosystem biotic structure, and 4) ecosystem function.

The main thrust within Component 1 is to reconstruct the past. Component 2 focuses on the analysis of historical and collected data on the hydrologic environment.

Component 3 deals with spatial and temporal distributions of populations. These three components support the studies of ecosystem function under Component 4. A brief description of major activities within each component is given in the remainder of this paper.

COMPONENT 1. SUCCESSION AND PERTURBATION

What is "long-term" to ecologists may be only "recent" to geologists, but there is a time span of mutual interest. In the Large Rivers LTER project we are developing a 200-year history of the sites from pollen contained in layers of sediment and tree ring chronology. In addition to providing a historical perspective, the physical sciences are proving useful in mapping the biological communities and in modeling the flow of organic carbon in the system. The geologic maps of bottom sediments in the river pools have been used as a predictor for mapping biological communities. For studying the flow of organic carbon we need to consider loss of carbon to bottom sediment, which is a significant factor in those areas of the rivers known to be filling with sediment.

Our three sites have a common geological history but differ significantly in modern geological processes. Our sites, and most of the large river systems in Illinois, were carved by the meltwaters of several episodes of glaciation. Through several cycles the valleys were deepened into bedrock during the period of maximum flow of glacial meltwaters and then partially filled by sediment during post-galcial times. In our sites this process has been accelerated by construction of the navigation lock and dam system and by the increased rate of sediment influx caused by modern agriculture.

Today, Peoria Lake and most of the backwater lakes of the Illinois River are filling with sediment at rates of 1 or more cm per year. This sedimentation provides a record of the introduction and transport of pollutants in the system. An upstream lake (DePue at mile 212) contains sediment with up to 5000 ppm zinc and up to 200 ppm lead, while a downstream lake (Silver at mile 3) contains sediment with concentrations of 120 ppm zinc and 30 ppm lead.

Pool 26 at Alton, Illinois, is not accumulating great quantities of fine-grained sediment, but it is subject to significant changes with the construction of the replacement lock and dam downstream of the existing lock and dam. The bottom sediments in Pool 26 were mapped by Goodwin and Masters (1983), who reported that the course of the Mississippi River has changed little since the development of European-American culture in the Midwest.

Pool 19 is accumulating vast quantities of fine-grained sediment. With the closure of Lock and Dam 19 in 1913, the pool began filling with sediment at the rate of 1.5% of volume per year and continues filling today at the rate of 0.6% per year. Measurement of this overall rate and calculation of the deposition rates of organic carbon in each ecological habitat area are key elements in our modeling efforts. Geological mapping of the full 70-km length of the pool has been completed. Grab samples of bottom sediment from 377 sites, 60 sediment cores, and many bathymetric cross sections were used to define 12 sediment types (Casavant, in preparation) and to prepare a geological map of bottom sediment in the entire pool. There is a significant trend of downstream fining in the sediment, indicative of active accumulation of sediment in the pool. Repetitive measurements of bathymetric cross sections in 1891, 1928, 1936, 1946, and 1983 show substantial aggradation in the lower one-third of the pool. Sedimentation rates range from highs of 14 cm per year near the downstream dam to zero in the upper end of the pool.

Cesium-137 is one of several isotopes that can be used to provide dates of sediment. This isotope was produced by the atmospheric testing of atomic weapons and began to be deposited in 1954. Deposition ended in 1970 with the end of testing of these weapons. Figure 3 illustrates this history, and figure 4 shows the quantities measured in a sediment core from Millman Lake, a backwater lake on Pool 19. Significant quantities of Cesium-137 were measured in the uppermost 45 cm of sediment in this core, but none was detected in the lower portions of the core. Thus we concluded that the upper 45 cm of sediment was deposited after 1954, probably mostly after 1963, and we can calculate an average sedimentation rate of about 2 cm/year. Similar measurements made on ten other sites have revealed sediment deposition rates ranging from 0.6 to >3.5 cm/year.

COMPONENT 2. HYDROLOGICAL ENRIVONMENT, WATER, SEDIMENT, AND MATHEMATICAL MODELING

The analyses of the water and sediment environment at the LTER project sites include the following:

a. Measure of water and sediment inflow and outflow.
b. Analyses of historical records to determine the past hydrological environment and to predict future changes.
c. Development, modification, and calibration of a water and sediment flow-mathematical model to determine the distribution and pattern of erosion and scour within the river environment and to predict future changes.
d. Determination of the inflow, outflow, and distribution of the carbon and nutrient fluxes through the research sites.

During the last three years, the major research activities within this component were concentrated on Pool 19 of the Mississippi River. Initially data on water and sediment discharges from about 22 tributaries and two main river sites were collected using standard methods (Buchanan and Somers, 1969; Guy and Norman, 1970). Figure 5 shows the locations of these sites. The tributaries range in drainage area from 55 to 11,200 km^2. Pool 19 has a local drainage area of 13,900 km^2, which is 4.5% of the drainage area at Lock and Dam 19. The Skunk River drains 80%, Henderson Creek drains 11.1%, and smaller tributaries drain the remaining 8.9% of the local drainage area. The data on water and sediment inflow and outflow are being utilized to develop a sediment and water budget for Pool 19 (Bhowmik and Adams, in press; Adams and Bhowmik, 1983).

Other data being collected from Pool 19 consist of the measurements of circulation and retention patterns within the channel border areas of the Montrose Flats (Adams and Bhowmik, 1984). Vane and float assemblies are used to collect these data where the flow velocities are extremely low. Presently electromagnetic current meters are also being used to determine the two-dimensional velocity distribution. These data are being collected to determine the impact of local flow patterns on the deposition and retention of sediment, carbon, and other nutrients within this segment of the river that may change the structure and function of biological communities.

At present mathematical models determining the distribution of particulate matter transport and deposition within the pool environment are being calibrated and verified. Initial emphasis has been on one-dimensional steady state hydrological models, including sediment transport. Two-dimensional models of the transport, scour, and deposition of sediment particles and water movement will be used to obtain necessary details in important habitats.

Some preliminary data on the mixing and sediment and water budget on Pool 26 near the confluence of the Illilnois and Mississippi Rivers have been collected. Data collection at this location will be continued with emphasis on the mixing of the flows from the two rivers.

Other hydrologic data include precipitation and suspended sediment distribution between the main channel and channel border areas, side channels, and sloughs.

Future data collection will include tributary and main channel sampling for water and sediment flows; intensive investigation of the retention mechanism on Montrose flats; determination of erosion, scour, and flow patterns at islands, side channels, and sloughs, especially during high flows; and collection of detailed water and sediment distribution data at selected sites for the verification of the mathematical models.

COMPONENT 3. ECOSYSTEM BIOTIC STRUCTURE

Studies of the biotic structure at the Illinois and Mississippi River LTER sites have centered on the following major areas:

a. Identifying the species composition of the major biotic components of this ecosystem.
b. Examining specific habitats in relation to characteristic biota or temporal utilization by particular biotic groups.
c. Determining longitudinal and latitudinal shifts in density and diversity of organisms at each LTER site.
d. Establishing techniques and sampling locations for continuation or development of long-term biotic data sets.
e. Developing a dynamic, predictive model to simulate short-term transfer of energy through a navigation pool and long-term changes caused by a succession of catastrophic events.

On the basis of previous data and initial studies under the LTER program, a series of sampling stations have been established at each of the LTER study sites. These include 10 in Peoria Lake of the Illinois River, 15 with 10 alternates on Pool 26 on the Mississippi-Illinois Rivers, and 12 with 10 alternates on Pool 19, Mississippi River. These sites include at least one sampling station in each of the major habitat types found in the pools. Unless site specific questions are being evaluated, each station on each pool is sampled at least seasonally.

The initial phases of this research determined the species composition and density of macrophytes, phytoplankton, zooplankton, benthic meiofauna, macroinvertebrates, and fish. These studies indicated that very specific relationships between habitat and species composition occur at all study sites. Thus, channel border areas with a mud substrate may be described as *Musculium* and/or *Hexagenia* macroinvertebrate communities based on their high density and biomass in this habitat. Shallow channel border areas and some backwaters develop relatively monotypic stands of vegetation (J.W. Grubaugh et al., "Production of *Sagittaria latifolia* and

Neulumbo lutea on Pool 19, Mississippi River," paper submitted for publication in Aquatic Botany).

Besides species specific habitat associations, invertebrates also showed strong density and diversity relationships. Due to high densities (up to 100,000 *Musculium*/m^2 and 3000 *Hexagenia*/m^2) and their dominance in channel border areas, biomass is high while diversity is low. In macrophyte beds, dominance and density are low with a corresponding low biomass but high diversity (including mollusks, annelids, and a variety of insects). Phytoplankton are dominated by diatoms and exhibit pronounced seasonality (figure 6d) (Engman, 1984). Zooplankton are dominated by rotifers but with higher densities of Cladocera and copepods in shallow channel border areas (figure 6b) (Pillard,, 1983). Zooplankton also showed temporal variation with maximum densities occurring in fall and longitudinal change with highest density in lower pool reaches (D.A. Pillard and R.V. Anderson, "A survey of the zooplankton of Pool 19, Mississippi River," paper submitted for publication in Hydrobiologia).

Longitudinal distribution of other invertebrates within pools shifts from communities dominated by insects (Hydropsychidae) in the upper pool reaches to a mussel-annelid dominated community in the lower reaches (figure 6a). In general, these trends are true at each of the study sites although specific densities and community compositions vary. For example, Pool 26 usually has lower densities of organisms with a different genus of Hydropsychidae occupying the niche of filtering collectors found on hard substrate (Anderson and Day, in press).

A number of specialized communities have also been described. These include the commercially valuable unionid mussel beds found in the river. From 10 to 26 species of mussels have been collected at the various LTER sites, with the greatest diversity in Pool 19. Densities range from 2 to 40/m^2 depending on continuous or random distribution. The invertebrate drift community supplies a comparatively constant trophic resource in the water column (figure 6c). There are numerous parasitic associations, such as *Plistophora* on rotifers (D.A. Pillard and R.V. Anderson, "A note on the parasitism of Rotifera by *Plistophora* in Pool 19, Mississippi River," paper submitted for publication in American Midland Naturalist), and inquilinistic associations, such as the trichopteran, *Oecetis*, pupation on mussels (Anderson and Vinikour, 1984) and the oligochaete, *Chaetogaster*, and asiatic clam, *Corbicula* (D.J. Holm and R.V. Anderson, "*Chaetogaster limnaei* infesting unionid mollusks and *Corbicula fluminea* in Pool 19, Mississippi River," paper submitted for publication in American Midland Naturalist). Meiofauna, nematodes, and rotifers have been found abundantly in selected habitats particularly associated with organic matter (R.V. Anderson, "Distribution of nematodes in Pool 19, Mississippi River," paper submitted for publication in Hydrobiologia).

Studies of fish/habitat associations on both rivers grew out of a previous long-term electrofishing program on the Illinois River (Sparks and Starrett, 1974). This program included stations at many points along the river but only in main- and side-channel habitats. Its objective was to address biological changes associated with water quality degradation from point sources. The present program still provides this kind of information. For example, in recent years our results have complemented observations of fishermen and fish managers on the upper Illinois River that improvements in the fishery related to improved water quality. By including additional habitats and sampling methods in the program, we now obtain more comprehensive data on entire fish communities in the rivers. Furthermore, standard methods for obtaining accessory data on water velocity, temperature, dissolved oxygen, conductivity, turbidity, depth, and presence of numerous cover and substrate characteristics have been incorporated into the program to help explain spatial or temporal changes in fish populations.

A subset of the data collected in 1983 was used to examine changes in fish activity in main channel border habitats in the lower Illinois River during a short-term drought and subsequent low discharges. Hoopnet results showed that dominant fishes changed from riverine- to backwater-associated species when current velocities dropped below 0.3 m/sec. When velocities remained below this level, movement of centrarchids between main channel border and backwater habitats appeared to be controlled by preference of fish for cool water. We concluded that during periods of low flow, lower Illinois River main channel borders provide suitable, if not preferred, habitat for species that are usually associated with backwaters. From a broader perspective, the results illustrated that functional roles of floodplain river habitats can be flow dependent even near the low end of the flow spectrum.

In addition to their biological value, most of our results have applications to floodplain fisheries management. A comparison of Illinois and Mississippi River fish populations showed that carp were typically smaller and in poorer condition in the Illinois River. Subsequent age analyses (Lubinski et al., 1984) indicated that Illinois River carp had shorter life spans and grew more slowly after their third year than those in the Mississippi. Evidence compiled from previous studies suggested that these population conditions were most probably related to poor food resources in the Illinois River, and indicated that the carp commercial fishery would benefit from any efforts to restore benthic populations (i.e., fingernail clams and mayflies) to their historical high levels.

Data are being used to produce a model predictive of species interactions, trophic relationships, and habitat associations. Continued sampling at the established long-term sites will be used to validate the model as well as to assess the effect of catastrophic events and long-term succession.

COMPONENT 4. ECOSYSTEM FUNCTION

The goal of this component is to answer the "why" and "how" questions about large rivers. Why are large floodplain rivers so productive, in terms of fisheries for example? Why are the biological community structures the way they are? How does the ecosystem work?

Our approach to answering these questions is to measure and model the flow of carbon through the system. Carbon is fixed by photosynthesis within the aquatic portion of the river itself and introduced as organic matter from the floodplain and tributaries. Carbon can enter food chains, be stored temporarily on the floodplain or bottom of the river, or be permanently lost to the biotic communities by deep burial within sediments.

The form of organic matter is important. Not all forms of organic matter are equally nutritious, and the nutritional value governs rates of utilization and decomposition by organisms and hence the rate at which carbon cycles within the system. The turnover rate of carbon in the leaves of some aquatic plants, from the time the carbon is fixed to the time the leaf senesces and decomposes, is measured in weeks while woody debris takes years to decompose, primarily because the nitrogen content of wood is too low to support consumers or decomposers which cannot derive nitrogen from the atmosphere or from other organisms. Although the standing crop of wood in the floodplain and bottom of the river is large, the contribution to aquatic food chains is small because the turnover rate is low.

Our measurements have already demonstrated the importance of carbon fixation in aquatic plant beds and marshes along the river. One of the most abundant emergent species, arrowhead (*Sagittaria latifolia*), produces at least 724 grams dry weight of organic matter per square meter per year. This is about half the production rate achieved on fertilized fields of corn (*Zea mays*), but more than most non-cultivated terrestrial plants. Our calculations of production for arrowhead and several other aquatic plants will be revised upward because we are just now measuring below-ground production of roots and leakage of dissolved carbon from stems and leaves.

We are currently investigating the fate of organic matter produced in plant beds. We already know that it does not accumulate in the sediments, so it is either used by primary decomposers within the beds or exported to other riverine habitats. The Water Survey is investigating secondary circulation patterns and the recurrence intervals of summer storms with strong winds which could generate waves and move organic matter out of plant beds. If this organic matter is exported and does fuel the detritus-based food chains, then aquatic plants provide a pulse of material at a critical time: the summer low flow period when the input of organic matter from floodplain and tributaries is minimal and phytoplankton populations are low.

The field measurements of carbon fixation, transport, and utilization are used in a computer model which simulates the functioning of the river ecosystem. Carbon is the "currency" which is exchanged between components of the biological model (for example, when predators eat prey). Population densities of key species are represented in grams of carbon per unit volume or unit area. The model includes nonliving components, such as dissolved organic carbon. The biological model is driven by a hydrological model which computes water flows and determines whether sediments will be scoured or deposited.

The model is explanatory, rather than expirical, so that any discrepancy between the behavior of the model and the real river leads us to rethink our concepts about how the river ecosystem works. We should be able to verify the capacity of the model to represent rare events (such as droughts and floods), which may produce major or long-lasting effects, because such events will occur during the 30-year life of the project and the response of the system will be measured.

Although the main purpose of the project and the model is to improve our understanding of rivers, both should find practical application in river management. We should be able to predict the likely effects on the river of proposed improvements in waste treatment and soil conservation in the basin and the effects of projected increases in barge traffic.

LTER AND LOCAL EDUCATIONAL INSTITUTIONS

The Illinois Rivers LTER project encompasses multifaceted research activities involving biology, hydrology, geology, chemistry, and other disciplines. Extensive historical data on the Illinois and Mississippi Rivers are available within the three Scientific Surveys, the State Museum, and Western Illinois University. Moreover, detailed data on almost all facets of river ecosystems are being collected by the researchers working on the project. This research not only is producing interesting and stimulating results, but also has raised a number of research questions and topics that cannot be answered within the present framework of the project. Additional research on these questions should be initiated in cooperation with other investigators.

The Illinois Rivers LTER research team would welcome the opportunity to initiate and develop joint research projects with professors and scientists at other colleges and institutions, especially those located along the Illinois and Mississippi Rivers.

FUTURE OF THE ILLINOIS RIVERS LTER PROJECT

The researchers propose to continue the project for a total of 30 years. The project is reviewed and funded in five-year installments. Although hypotheses and methodological details may change, the basic direction of the research will remain the same with an emphasis on long-term evaluation with related short-term experimentation. It is certain that innovative concepts and interdisciplinary approaches will be required before we can arrive at an intellectually satisfying understanding of the ecology of large rivers.

ACKNOWLEDGMENTS

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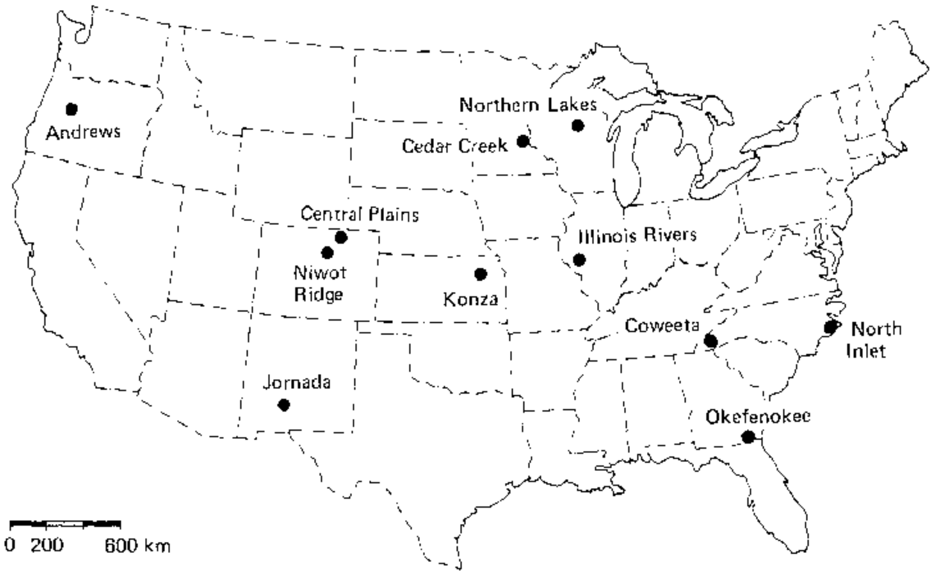

Fig. 1. Long Term Ecological Research (LTER) Network

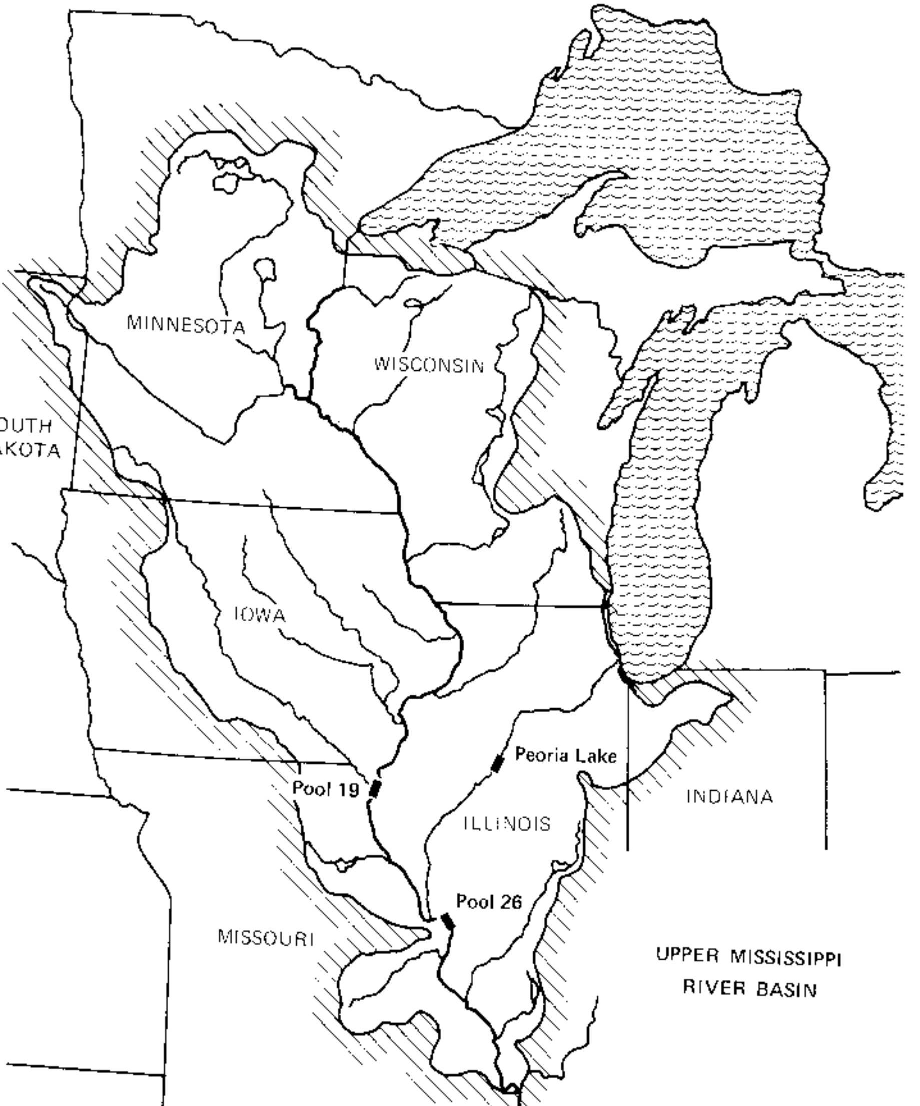

Fig. 2. Illinois Rivers LTER sites

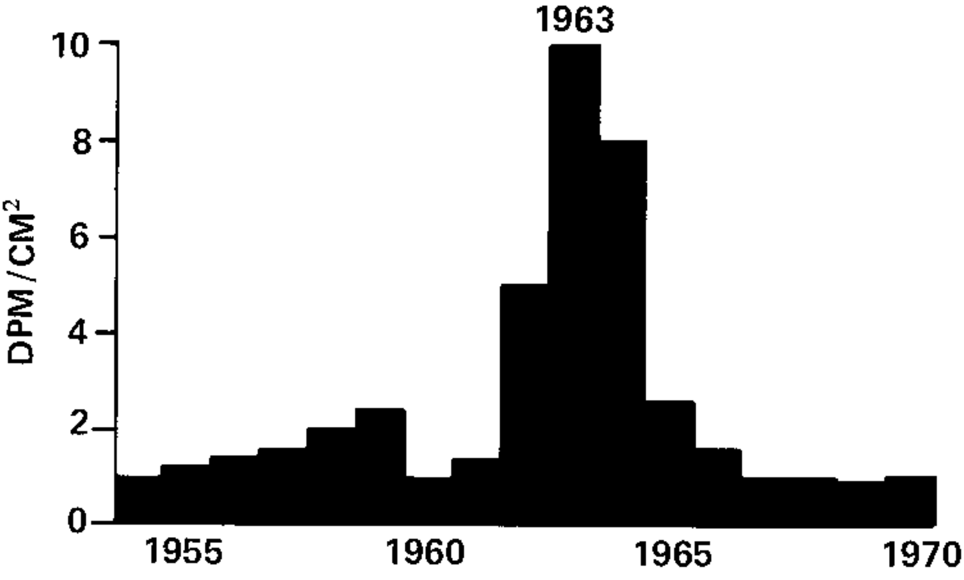

Fig. 3. Atmospheric deposition of Cesium-137 in the Northern Hemisphere

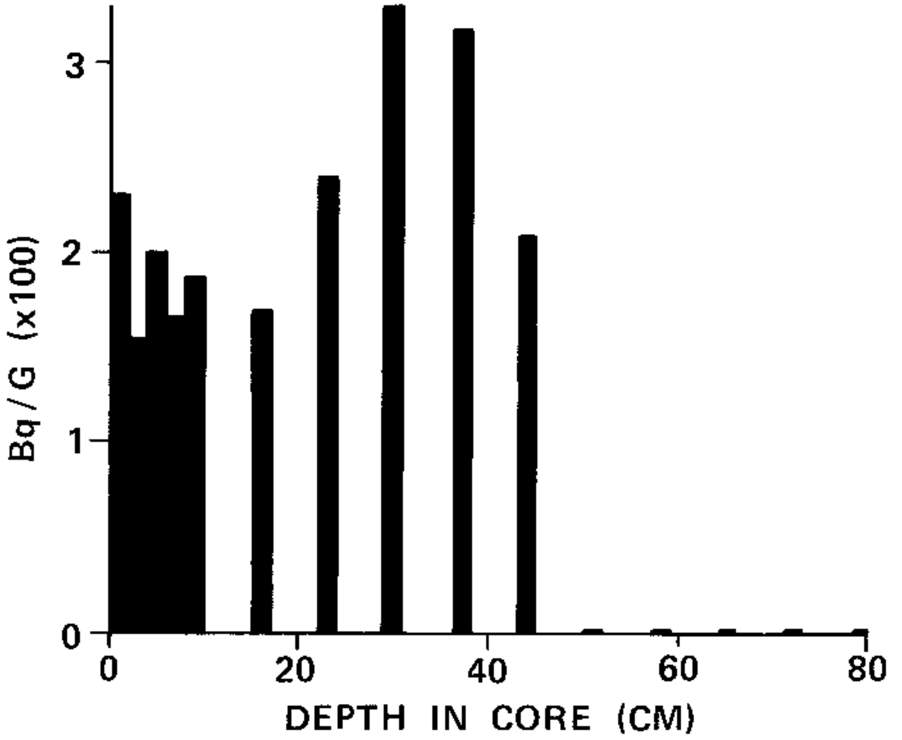

Fig. 4. Cesium-137 profile, Millman Lake, Pool 19

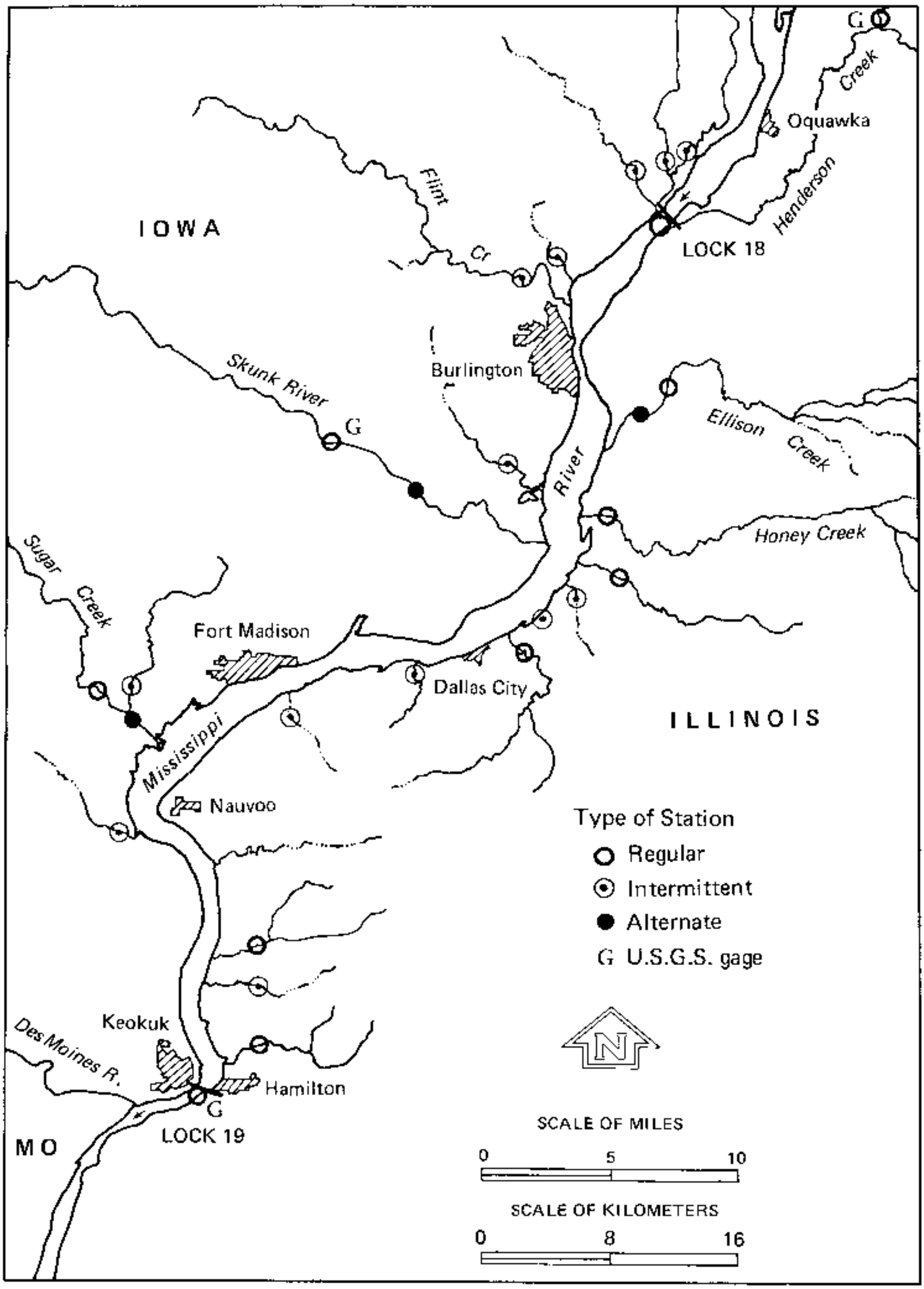

Fig. 5. Pool 19 on the Mississippi River with suspended sediment stations

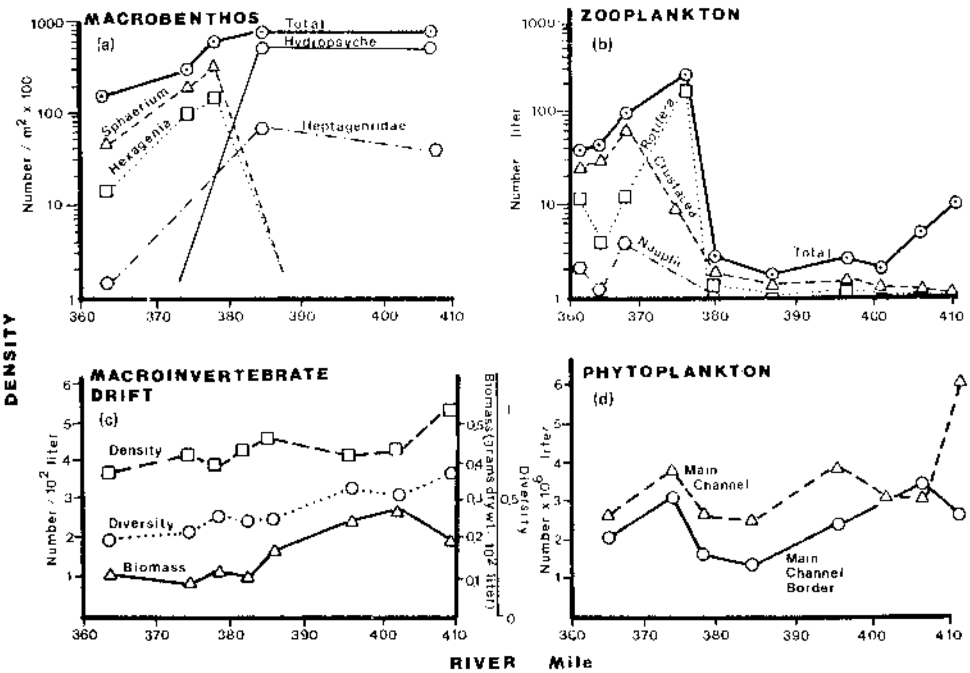

Fig. 6. Longitudinal distribution of major biotic components found in Pool 19, Mississippi River: a) benthic macroinvertebrates, b) zooplankton, c) macroinvertebrate drift, d) phytoplankton