SUMMARY OF BIOLOGICAL INVESTIGATIONS RELATING TO WATER QUALITY IN THE WESTERN LAKE MICHIGAN DRAINAGES, WISCONSIN AND MICHIGAN

By Barbara C. Scudder, Daniel J. Sullivan, Stephen J. Rheaume, Scott R. Parsons, and Bernard N. Lenz

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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Multiply	By	To Obtain
inch (in)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.09294	square meter
square mile (mi^2)	2.590	square kilometer
acre	0.0040485	square kilometer
gallon (gal)	3.785	liter
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

Temperature, in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by use of the following equation:
$°F = 1.8 \times °C + 32.$

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Summary of Biological Investigations Relating to Water Quality in the Western Lake Michigan Drainages, Wisconsin and Michigan

By Barbara C. Scudder, Daniel J. Sullivan, Stephen J. Rheaume, Scott R. Parsons, *and* Bernard N. Lenz

Abstract

This report summarizes aquatic biological studies relevant to water–quality assessment that have been done in the Western Lake Michigan Drainages from 1891 to 1996. The objective of the summary was to compile sources of biological data for the U.S. Geological Survey's National Water-Quality Assessment Program. The studies are divided into four categories: (1) populations and community structure of aquatic biota, (2) health of aquatic biota, (3) chemical concentrations in tissues of aquatic biota, and (4) toxicity tests by use of aquatic biota. Studies are further categorized by subbasin, spatial scale (regional or local), types of biota, and, if applicable, effect or contaminant investigated. For the purposes of this report, the study area is divided into five subbasins. The subbasins, from north to south, are (1) the Ford/Escanaba Subbasin in Michigan's Upper Peninsula, and in Wisconsin, (2) the Menominee/Oconto/Peshtigo Subbasin, (3) the Fox/Wolf Subbasin, (4) the Sheboygan/Manitowoc/Twin Subbasin, and (5) the Milwaukee Subbasin.

Most biological studies related to water-quality conditions in the Western Lake Michigan Drainages have focused on populations and community structure of aquatic biota. Chemical concentrations in tissues of aquatic biota have been the next most common area of research. Our review suggests a paucity of data related to the health of all types of aquatic biota, especially amphibians, invertebrates, and reptiles; toxicity studies also were relatively uncommon. Overall, organisms primarily studied have been fish and invertebrates, although birds are most frequently examined in studies of organism health. The Fox/Wolf Subbasin has been the focus of many more studies than the other subbasins, most likely because of the greater extent and severity of known water-quality problems in the Lower Fox River/Green Bay area over the past several decades and because it is the largest subbasin. Studies in the other subbasins are needed to adequately assess the water quality of these areas.

INTRODUCTION

Biological data are a critical component of water-quality assessments because biota can be sensitive indicators of environmental status and change. Biota respond to various natural and anthropogenic stressors, and they can integrate temporal changes in water quality. These responses may occur at several levels of biological organization: ecosystem, community, population, and organism. At the ecosystem and community levels, the variety of organisms, or biodiversity, may be altered as a result of adverse environmental changes. Populations of some organisms may be reduced to the point where certain species are endangered, threatened, or of special concern, while other organisms may thrive and dominate. Organisms may react to environmental stressors by changes in their physiology, morphology, reproduction, and (or) behavior. Some contaminants may become concentrated in aquatic organisms and may reach levels that could affect the health of predator organisms as well as humans. Studies of biota are thus vital indicators of water quality and can provide important information for the protection of aquatic resources.

The National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey was designed to "(1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's water resources, (2) define long-term trends (or lack of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect observed water-quality conditions and trends" (Hirsch and others, 1988). The NAWQA Program is an integrated assessment of water quality that includes multiple lines of evidence from physical, chemical, and biological data. Biological investigations of interest to NAWQA include studies of aquatic habitat, community structure of aquatic biota, and the occurrence and spatial distribution of contaminants in target species of biota. The Western Lake Michigan Drainages Study Unit is one of 20 study units across the nation in which work began in 1991.

Purpose and Scope

The purpose of this summary is to identify the sources of biological data in the Western Lake Michigan Drainages study area and to evaluate their relevance to water-quality assessment. This effort provides retrospective biological data for the NAWQA Program. Although some useful but unpublished biological information also is available, the authors have chosen to restrict the scope of this report to published material and data available from Federal, state, or local programs. Four categories of studies of aquatic biota are discussed: (1) populations and community structure, (2) health of aquatic biota, (3) chemical concentrations in tissues, and (4) toxicity tests. Studies are further categorized according to subbasin, spatial scale (regional or local), types of biota and, if applicable, the effect or contaminant investigated. Studies on biota that are in the aquatic environment during all or part of their life cycle are included, with the exception of bacteria, fungi, and mammals. Publications and programs from the earliest available years through present (1891 to 1996) are categorized and evaluated with respect to their utility for water-quality assessment. Common trends in water quality indicated by the studies are discussed. Comparability among studies and length of studies were not examined but would provide valuable information for planning future research in the study area.

Researchers from Federal, state, local, and academic organizations investigate aquatic biology in the study area. Reports cited in this study were obtained through contacts with researchers, searches of bibliographic data bases, and manual searches of literature. Numerous graduate student theses on biological topics were obtained. Bibliographies of selected topics also were reviewed for pertinent reports (Harris and Pletcher, 1992; Watermolen, 1992c). An inventory of nearly 700 research projects in the Great Lakes area was published by the International Joint Commission (1992). The covered projects are from various institutions and agencies in the U.S. and Canada. This inventory also is available in electronic form. Project FIRST (Field Involvement—Research by Science Teachers) of the Wisconsin Academy of Sciences, Arts, and Letters supports a number of aquatic biological studies by elementary school teachers and students in Wisconsin through funding by the National Science Foundation (Lake, 1995). Most of the data and publications summarized in this report are from studies by researchers from the Wisconsin Department of Natural Resources (WDNR), the Michigan Department of Natural Resources (MDNR)[1], the U.S. Fish and Wildlife Service (USFWS), the U.S. Environmental Protection Agency (USEPA), the University of Wisconsin, the University of Michigan, and Michigan State University.

Western Lake Michigan Drainages Study Area

The Western Lake Michigan Drainages study area drains approximately 51,000 square kilometers in eastern Wisconsin and the Upper Peninsula of Michigan (fig. 1). For this report, the study area is divided into five subbasins. In Michigan's Upper Peninsula, the Ford/Escanaba Subbasin (Subbasin 1) drains forests and forested wetland south to Green Bay. The Menominee/Oconto/Peshtigo Subbasin (Subbasin 2) drains mostly forested lands to Green Bay. The Fox/Wolf Subbasin (Subbasin 3), the largest system in the study area, extends west into the central agricultural region and north into an area of lakes and forests. It includes Lake Winnebago, the pulpmills and papermills along the lower Fox River, and the metropolitan Green Bay area, where the mouth of the Fox River empties into the southern end of Green Bay. The Sheboygan/Manitowoc/Twin Subbasin (Subbasin 4) lies east of Lake Winnebago and includes the Door Peninsula. This mainly agricultural region drains directly into Lake Michigan. The Milwaukee Subbasin (Subbasin 5) is composed of agricultural land and the Milwaukee urban area.

[1]In 1995, the Michigan Department of Environmental Quality (MDEQ) was established; This agency now manages the surface water-quality assessment duties that had been performed by the MDNR.

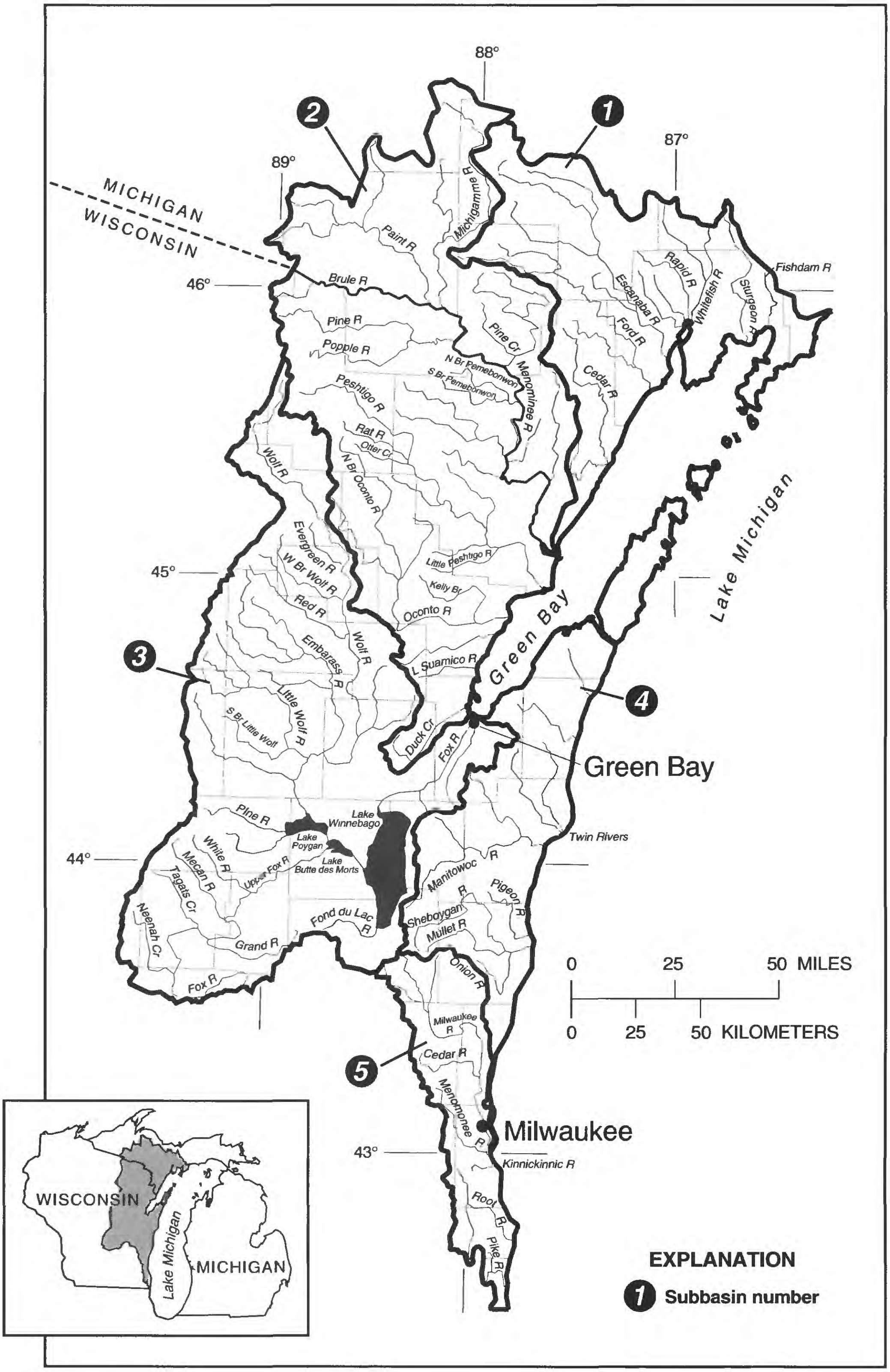

Figure 1. The five subbasins of the Western Lake Michigan Drainages study area: (1) Ford/Escanaba Subbasin, (2) Menominee/Oconto/Peshtigo Subbasin, (3) Fox/Wolf Subbasin, (4) Sheboygan/Manitowoc/Twin Subbasin, and (5) Milwaukee Subbasin.

The bedrock of the study area consists of igneous and metamorphic rocks in the northwest, mostly carbonate rocks in the east, and sandstone in the southwest (Robertson and Saad, 1995). Surficial deposits consist primarily of unconsolidated glacial, fluvial, and eolian materials. The texture of these deposits is classified as predominantly sand or sand and gravel in the north and west and as clay in the southeast. Loam covers some north and central areas, and small peat deposits are found in the Michigan part of the study area (Robertson and Saad, 1995).

The ecoregions in the study area, as delineated by Omernik and Gallant (1988), are the Northern Lakes and Forests, North Central Hardwood Forests, Southeastern Wisconsin Till Plains, and Central Corn Belt Plains. Ecoregions are areas of relatively homogeneous land use, potential natural vegetation, soils, and land-surface form. These areas were delineated by Omernik and Gallant (1988) as a means of summarizing important factors affecting ecosystems.

Overall, wetland covers approximately 15 percent of the land in the study area. Eighty-nine percent of this wetland is forested, and it is mainly in the northern part of the study area. Most of the unforested wetland is along the upper Fox River, the lower end of the Wolf River, and the middle reaches of the Escanaba River (David Saad, U.S. Geological Survey, Madison, Wis., written commun. 1993). According to an inventory of data compiled by the State of Wisconsin, roughly 30 percent, or 6,500 square kilometers, of the State's remaining wetland is in the study area (Wisconsin Department of Natural Resources, 1994). In Delta and Menominee Counties of the Upper Peninsula of Michigan, there are 43 square kilometers of coastal wetland along Lake Michigan. No other specific data were provided on wetland area in the Michigan region of the study area in Michigan's 1994 Report to Congress (Michigan Department of Natural Resources, 1994b).

Historical Water-Quality and Biological Conditions

In general, water quality of rivers and lakes in the northern forested region of the study area (Subbasins 1 and 2, and northern areas of Subbasin 3) shows little effect of human activity, and aquatic communities in these water bodies are more representative of unaltered conditions than are those of more southern streams, which may be significantly altered by human activity. Large areas of wetland, especially forested wetland, are found in this northern region. Water-quality problems are mostly related to nonpoint pollution or habitat modification (Michigan Department of Natural Resources, 1994b). Mining, septic systems, and landfills are some problem sources. Extensive areas of the northern forested region have been logged. Clearcut logging and creation of inadequate buffer strips along streams contribute to increased runoff and siltation.

Land use in the southern part of the study area (Subbasins 4 and 5, and the southern areas of Subbasin 3) is primarily agriculture. Habitat modification, excessive application of nutrients on soil, herbicide and pesticide use, increased soil erosion and runoff, vegetation removal, livestock grazing, and channelization have resulted in degraded water quality in many areas. As in the northern forested region, creation of inadequate buffer strips along streams contributes to increased runoff and siltation. Specific land-use-management practices, known as Best Management Practices, have been implemented in some agricultural basins in an effort to reduce nonpoint pollution and improve water quality (Wisconsin Department of Natural Resources, 1994; Stuntebeck, 1995).

Streams in the urban and industrial parts of the study area generally are known to have degraded water quality and low diversity of aquatic biota. Urban runoff and industrial contamination have led to poor water quality in many areas. In the study area, the International Joint Commission has named four Great Lakes Areas of Concern, areas identified as severely degraded because of urban and (or) industrial contamination (Hartig and Law, 1994). The Areas of Concern are: Menominee River at the mouth, Lower Fox River/southern Green Bay, Sheboygan River at the mouth, and Milwaukee Estuary. Contamination of water and sediment at these locations have been associated with detrimental effects on the aquatic biota. Papermills have discharged into the lower Fox River for decades and have contributed to elevated levels of contaminants in biota and sediments found there. Water quality in the lower Fox River has improved since the 1970's as a result of installation of new sewage-treatment plants and various cleanup efforts (Leung and Sell, 1982; Harris and others, 1982, 1988).

Aquatic Communities in the Western Lake Michigan Drainages

Composition of aquatic communities in the study area reflects the large range in latitude from the northern to the southern parts, the variety of current and historical land uses, and other environmental influences. Introductions of exotic species also affect communities in the study area because these species prey on and compete with native species for space and food. The following section is a general description of plants, invertebrates, and vertebrates that make up the aquatic communities of the study area.

Macrophytes. Large aquatic plants, referred to as "macrophytes," include vascular plants, mosses, liverworts, large algae, and other plants that are visible to the unaided eye (Sculthorpe, 1967). Growth forms of macrophytes range from submersed to emergent to floating, depending on the species and maturity of the plant. About 51 families of macrophytes are represented in Wisconsin and the Upper Peninsula of Michigan (table A1), many of which are found in streams of the study area. The pondweed family Potamogetonaceae is represented by the largest number of submersed species (25) and a wide variety of growth forms. Several introduced macrophytes, such as eurasian watermilfoil (*Myriophyllum spicatum*), have become dominant members of some aquatic communities in the study area (Sabol, 1983; Welsch, 1988). Purple loosestrife (*Lythrum salicaria*), an introduced emergent with tall purple "spike" flowers, has invaded many lakeshores and wetland in the study area by outcompeting native species. Excessive growth of purple loosestrife can impede water flow as well as replace native plants that are of greater benefit to other organisms (Welsch, 1988; Wisconsin Department of Natural Resources, 1990; Walters, 1992).

Aquatic Invertebrates. At least 150 families and several thousand species of aquatic invertebrates live in the study area (Edmondson, 1959; Pennak, 1989; Hilsenhoff, 1981; Thorp and Covich, 1991; Detwiler and others, 1991). Of the many taxa of invertebrates found in the study area (table A2), the four groups most commonly assessed in water-quality studies are insects, crustaceans, mollusks, and worms. Many of these invertebrates live in or on streambed sediments where contaminants tend to concentrate; thus, the chance the organisms may react to toxic substances is increased.

Insects, by far the most diverse aquatic invertebrates in the study area, represent 10 orders. Stoneflies (Order Plecoptera) are represented by nine families (about 70 species) in the study area. Most stonefly nymphs are intolerant of pollution and are found in stream areas where concentrations of dissolved oxygen are fairly high. These characteristics may account for their absence in most streams in agricultural areas of southern Wisconsin. Fourteen families (about 150 species) of mayflies (Order Ephemeroptera) are present. Nymphs of most mayfly species also require high concentrations of dissolved oxygen, but many are more tolerant of low dissolved oxygen concentrations than are stoneflies. Dragonflies and damselflies (Order Odonata), represented by at least eight families (130 species), are found primarily in ponds, marshes, and lake margins, but some species are present in streams. Approximately six aquatic families (75 species) and five semiaquatic families (30 species) of true bugs (Order Hemiptera) are present, including water striders, water bugs, treaders, water boatmen, water scorpions, and backswimmers. About 16 families (290 species) of caddisflies (Order Trichoptera) are distributed throughout the study area. Most caddisfly larvae and pupae inhabit streams, but some are found in other aquatic habitats. Some species of caddisflies are fairly tolerant of organic pollution. Larvae of fishflies and alderflies (Order Megaloptera) are common in both streams and lake habitats and are represented by two families (20 species). One family (five species) of spongilla fly larvae (Sisyridae, Order Neuroptera) is likely to be found in streams and lakes where the host sponge species is present. One family of aquatic moths (Pyralidae, Order Lepidoptera) is fairly common (15 species) in some lakes and streams. Twelve aquatic families (more than 350 species) of beetles (Order Coleoptera) are found in the study area, most in the families Dytiscidae, Gyrinidae, Haliplidae, Elmidae, Curculionidae, and Hydrophilidae. Approximately 20 families (more than 400 species) of aquatic flies and midges (Order Diptera) are found in the area's streams and lakes. Because the taxonomy of larvae in the numerous species of aquatic insects is poorly known, species lists are fairly tentative.

Some aquatic mollusks can live for ten or more years and may reflect long-term water-quality changes over comparable periods. In the study area, mollusks are divided into two classes: freshwater gastropods and freshwater bivalves (Burch, 1991). The gastropods are represented by the orders Mesogastropoda (6 families, 24 species) and Limnophila (4 families, 66 species). The bivalves are represented by the orders Veneroida (2 families, 31 species) and Unionoida (1 family, 46 species). An exotic bivalve, the zebra mussel (*Dreissena polymorpha*), was first reported in the United States in 1988 in Lake St. Clair near Detroit, and it has since invaded other waters, including Lake Michigan. The zebra mussel has been found in several harbors along the shoreline of the study area, including Green Bay, Kenosha, Manitowoc, Marinette, Milwaukee, Port Washington, Racine, Sheboygan, and Sturgeon Bay (University of Wisconsin Sea Grant Institute, 1996). This prolific freshwater mollusk has had a substantial economic impact in the Great Lakes region because it can rapidly colonize hard underwater surfaces including water intake pipes, boat hulls, buoys, and pilings. Many of the observed ecological effects of zebra mussels have been detrimental, including competition with and infestation of native invertebrates.

Crustaceans are an ecologically important group of aquatic invertebrates, and they are found in almost all environmental settings. They are an important food source for fish, making them an important organism in toxic bioaccumulation studies (Crawford and Luoma, 1993). Common aquatic crustaceans in the study area include the orders Isopoda (sow bugs; one family, five species), Anostraca and Conchostraca (fairy and clam shrimps; two families, five species), Decapoda (prawns and crayfish; two families, eight species), and Amphipoda (scuds; three families, eight species).

The Annelida (segmented worms) is the most often studied phylum of worms. Most freshwater annelids are related to earthworms (Oligochaeta) and leeches (Hirudinea). Four families (about 15 species) of Oligochaeta are found in the lakes and streams of the study area. Changes in their density and distribution in response to different kinds of pollution and toxic substances make them useful as water-quality indicators. Four families of Hirudinea (43 species) are found in the study area.

Amphibians and Reptiles. Amphibians and aquatic-associated reptiles are represented by relatively few species in the study area compared to other groups of biota (table A3). Eleven species of frogs and toads (Order Anura), and eight species of aquatic-associated salamanders (Order Caudata) are found in the study area. Most breed in ponds, lakes, wetlands, and wet areas along streams. The northern leopard frog (*Rana pipiens*) has the widest distribution, and members of this genus represent six of the ten species of frogs. Leopard frog populations appeared to decline in the 1970's but may now be stable (Watermolen, 1996a). Only one toad species, the American Toad (*Bufo americanus*), is found in the study area. Concerns over declines in amphibian populations in the study area have reflected apparent worldwide declines of these organisms. Aquatic-associated reptiles in the study area are represented by seven species of snakes (Order Squamata) and seven species of turtles (Order Testudines).

Fish. The streams in the study area are inhabited by a wide variety of fish species and communities (table A4). Coldwater streams are dominated by salmonids, cottids, certain cyprinids, and a few other species, whereas warmwater streams are dominated by a generally more diverse group of fishes including many cyprinids, catostomids, ictalurids, centrarchids, and percids (Lyons, 1996). A few species, such as the white sucker (*Catostomus commersoni*), tolerate a wide variety of temperature and water-quality conditions and thus are distributed throughout the study area. Coldwater fisheries are common in the northern and western parts of the study area. Some headwater streams in the southeastern part support coldwater species for short reaches, particularly if the stream is spring fed; however, most coldwater streams in the study area become coolwater or warmwater fisheries downstream as drainage area and stream order increase.

According to distribution maps and descriptions in Becker (1983) and Fago (1984, 1985, 1992), representatives from 24 families of fish (112 species) are known to inhabit the inland streams of the study area. The largest families, in terms of numbers of species, are minnows and carps (Cyprinidae; 35 species), followed by perches (Percidae; 14 species), suckers (Catostomidae; 11 species), and sunfishes (Centrarchidae; 10 species).

Birds. Birds in the study area are represented by 18 families (table A5) and 106 species. Many species are migratory, spending only part of the year in the study area. The family with the most species (30) is that which includes swans, geese, and ducks (Family Anatidae). A survey of breeding birds in Lakes Poygan, Winneconne, and Butte des Morts listed 87 species of birds (Mossman and others, 1984). The survey determined that at least 77 species of birds may nest around these lakes, including several state-listed endangered, threatened, and watch species. Forster's terns (*Sterna forsteri*) nesting by these three lakes account for a large part of Wisconsin's total nesting population (Mossman and others, 1984). In recent years, the double-crested cormorant (*Phalacrocorax auritus*), sandhill crane (*Grus canadensis*), bald eagle (*Haliaeetus leucocephalus*), and other species have made substantial recoveries in abundance in the study area (Scharf and Schugart, 1981; Mossman and others, 1984; Matteson, 1985; Postupalsky, 1989; Michigan Department of Natural Resources, 1995; Giesy and others, 1995; Hilsenhoff, 1995).

Endangered and Threatened Aquatic Biota. Seven species of aquatic biota on the Federal endangered or threatened species list are found in the study area (table A6). These species are the bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), dwarf lake iris (*Iris lacustris*), eastern prairie fringed orchid (*Platanthera leucophaea*), Fassett's locoweed (*Oxytropis campestris*), Houghton's goldenrod (*Solidago houghtonii*), and Pitcher's thistle (*Cirsium pitcheri*).

Many state-listed species considered to be endangered, threatened, or of special concern are found in the study area (table A7), many more than are on the Federal list. Species may be endangered or threatened within a state or region but common elsewhere in the United States; thus, they appear on state lists but not on the Federal list.

Biota as Water-Quality Indicators

Information on background or baseline conditions of biota and biotic communities is necessary to evaluate whether changes in biota have resulted from changes in water quality. Large-scale regional studies of biotic communities include studies of algae (Prescott, 1962), macrophytes (Modlin, 1970; Nichols, 1988; Nichols and Martin, 1990), insects (Hilsenhoff, 1975, 1981), mollusks (Mathiak, 1979), amphibians (Casper, 1996), fish (Becker, 1983; Fago, 1992), and birds (Gromme, 1963; Robbins, 1971, 1977, 1982; Temple and Cary, 1987; Granlund and others, 1994; Hilsenhoff, 1995). Several local-scale studies have addressed conditions in nearly pristine watersheds with respect to one or more types of biota (Smith, 1978; U.S. Geological Survey, 1995; Rheaume and others, 1996).

Information on changes in species composition and abundance of algae is often valuable for use as an indicator of water quality. Phytoplankton, such as some blue-green and green algae, may increase greatly in number in polluted or nutrient-rich waters. Marsh (1903) observed large blooms of several blue-green algae followed by a bloom of the green algae *Cladophora* during summers in Lake Winnebago. Algal blooms in the lower Fox River were common for decades as a result of elevated nutrient concentrations (Harris and others, 1988).

A diverse community of macrophytes is generally associated with good water quality. Smith (1978) observed 50 species of submerged, emergent, and floating macrophytes in streams and lakes of the Pine and Popple River watersheds in 1967 and 1968. This diverse assemblage reflected the relatively pristine nature of these watersheds in the northern forested region of the study area. Modlin (1970) did a survey of 23 lakes and ponds in the Milwaukee Subbasin and found that Long Lake and Big Cedar Lake, with 34 and 30 species of macrophytes, respectively, had the greatest species diversity. By the late 1960's, historically diverse and abundant growths of emergent and submerged macrophytes had mostly disappeared from Lakes Poygan, Winneconne, and Butte des Morts in the Fox/Wolf Subbasin. Populations of birds, dependent on the macrophytes, also eventually declined. Kahl (1993) suggested that high water levels and low water clarity in these lakes between 1975 to 1982 were the most important factors limiting growth of macrophytes in these lakes. Several recent studies have examined factors that influence light attenuation and the effects of these factors on re-establishment of submergent macrophytes in Green Bay (McAllister, 1991; Sager and others, 1996).

Profuse growths of single species of submerged macrophytes may result because of eutrophication and (or) biological factors. Coontail (*Ceratophyllum demersum*) and the nonnative eurasian watermilfoil (*Myriophyllum spicatum*) have become abundant in lakes in the southern half of the study area (Sabol, 1983; Welsch, 1988). Mechanical removal of plant beds has been used as a control method when densities of macrophytes have resulted in decreased recreational use of lakes (for example, see Sabol, 1983). Bumby (1977) documented the increasing eutrophication of Green Lake (Fox River watershed) by comparing current conditions to conditions 50 years earlier, as noted in a study by Rickett (1924).

Insect populations have long been used to evaluate spatial and temporal patterns of water quality (for example, see Hilsenhoff, 1977, 1982, 1987, 1988a, b; Michigan Department of Natural Resources, 1991a, 1994b; Summers, 1991). In 1977, Hilsenhoff (University of Wisconsin-Madison) created the Hilsenhoff Biotic Index of water quality (HBI) which assigns pollution-tolerance values to many aquatic insects, thus allowing for the evaluation of organic and nutrient stream pollution (Hilsenhoff, 1977, 1982, 1987). Water quality of sampled sites on Armstrong Creek, Chemical Creek, Lawrence Creek, Mecan River, Mullet River, Onion River, Peshtigo River, and Sidney Creek was "very good" to "excellent" in 1977 and 1978 on the basis of HBI values (Hilsenhoff, 1982). The site sampled on the Sheboygan River received an HBI value that indicated only "fair" water quality. Ankley, Lodge, and others (1992) observed a low diversity of benthic invertebrates in the lower Fox River compared to that for a reference location on the East River. High ammonia concentrations were postulated as one possible factor that has adversely affected this community.

Although amphibians and reptiles have been examined in the study area for many years, their relationship to water quality has only recently begun to be explored extensively. Amphibians and many reptiles rely on water bodies for all or part of their life cycle. Many species are sensitive to water-quality degradation and, in many cases, may be the first aquatic life forms to show the effects of degraded water quality (Mossman and Hine, 1985). Scientists are now becoming aware that declines in populations of these biota can be early warning signs of water-quality degradation (Evers, 1992). The WDNR Frog and Toad Survey (Mossman and others, 1991) indicates that populations of several species have declined statewide, possibly as a result of habitat loss and water-quality problems. Hine and others (1981) did a statewide investigation of leopard frog (*Rana pipiens*) ecology and suggested that high mortality, low reproduction, disease, and various internal and external abnormalities were contributing to the apparent decline of this species in Wisconsin. Jung and others (1996) found decreased diversity and abundance of amphibians along the lower Fox River compared to wetland sites near Green Bay. Leopard frogs and green frogs (*Rana clamitans*) showed reduced hatching success, and the hatching success of leopard frogs was negatively correlated with sediment PCB concentrations.

The long-term decline of many birds in the study area is thought to be a function of the loss of aquatic vegetation used for nesting habitat. The disappearance of once extensive areas of emergent and submergent macrophytes from the Fox River/Green Bay area began in the mid-1800's when water levels were raised by the Fox River dams. A rapid decline in macrophyte abundance in the mid-1970's was followed by declines in fish and birds (Harris and others, 1988; Kahl, 1993). Cormorants have historically been at odds with commercial fisheries in the Great Lakes region and elsewhere due to cormorant predation on fish trapped in nets (Matteson, 1983). Dramatic declines in their populations were observed in the late 1950's through the early 1970's, and these declines were attributed to human control methods, habitat loss, and bioaccumulation of contaminants such as DDT and PCB's (Anderson and Hammerstrom, 1967; Matteson, 1983, 1985; Ludwig, 1984). Protection measures such as artificial nesting platforms have resulted in great increases in the Michigan and Wisconsin populations in recent years. Techlow and Mossman (1985) found marked declines in numbers of nesting individuals for Forster's tern, herring gulls, and ring-billed gulls in the upriver lakes of the Winnebago Pool from 1984 to 1985. During this period they also observed a dramatic decline in the number of common tern (*Sterna hirundo*) nests, and noted poor fledging of Forster's terns at one island colony in Rush Lake. These researchers attributed the declines to habitat loss.

Wetland ecosystems provide a habitat for a high percentage of flora and fauna in the United States, especially for large numbers of endangered and threatened species. Wetland also plays a critical role in mitigating floods, decreasing erosion, and improving water quality. Wetland has proven to be a sink for organic and inorganic nutrients and toxic materials that flow through it and may also be an effective site for wastewater treatment (Tiner, 1984; Sager and others, 1984; Mitsch and Gosselink, 1986). However, the values of wetland have often been considered secondary to those of urbanization, agriculture, and logging. Statistics compiled by the WDNR and MDNR showed an approximate 50 percent loss of wetland area in Wisconsin and Michigan since pre-European settlement (Wisconsin Department of Natural Resources, 1994; Michigan Department of Natural Resources, 1994b) and Tiner (1984) reported that rates of wetland loss in Wisconsin and Michigan were 81 and 26 square kilometers per year respectively. On the west shore of Green Bay, Bosley (1978) listed conversion to agricultural land, water pollution, dredge spoil disposal, cottage settlement, and timber harvesting as apparent causes of wetland loss. The WDNR and MDNR either have established or have plans to protect wetland and develop water-quality standards for wetland in order to preserve their integrity (Wisconsin Department of Natural Resources, 1994; Michigan Department of Natural Resources, 1994b).

Studies of the health of aquatic biota in the study area underscore the prevalence of contamination in the Great Lakes region, and several studies have found increased tumor incidence in fish from Great Lakes tributaries (Black, 1983; Harshbarger and others, 1983; Baumann and others, 1987, 1991). Increased tumor incidence may be associated with elevated carcinogen concentrations in sediments, possibly PAH's. Baumann and others (1991), however, found no liver tumors in brown bullheads from the Fox and Menominee Rivers, even though tissues of these fish contained fairly high concentrations of polychlorinated aromatics. External tumors were observed in bullheads from the Fox (4 of 52 fish), and a liver tumor was observed in 1 of 40 walleye sampled from the river. Ankley, Lodge, and others (1992) found no tumors or liver lesions in their study of brown, black, and yellow bullheads from the lower Fox River.

Fish kills may result from low concentrations of dissolved oxygen, chemical spills, disease, or other factors that may not be known. Fish kills are generally reported to the WDNR or MDNR/MDEQ but may be underestimated because of elapsed time between occurrence and reporting and investigation. Officially reported fish kills are listed in the yearly water-quality reports to Congress (Michigan Department of Natural Resources, 1994b; Wisconsin Department of Natural Resoures, 1994). Six fish kills were officially recorded in the Wisconsin part of the study area from October 1991 through September 1993 in the Menomonee River, Honey Creek, Buffalo Lake, Menominee River, and two in Green Bay (Wisconsin Department of Natural Resources, 1994). Historical fish kills in the lower Fox River occurred as early as 1924. These fish kills were thought to be due to high biological oxygen demand (BOD) and the resultant anaerobic conditions that plagued this river for decades (Balcer and others, 1986). Fish kills were common on the lower Oconto River before remediation efforts (Rost, 1983). No fish kills were reported in the Michigan part of the study unit in the most recent water-quality report to Congress (Michigan Department of Natural Resources, 1994b).

Several studies have found reproductive impairment and malformations in birds from the lower Fox/Green Bay area (Trick, 1982; Kubiak and others, 1989; Fox, Collins, and others, 1991; Ankley, Lodge, and others, 1992; Harris and others, 1993; Hoffman and others, 1993; see also Harris, 1988). The frequency of malformations in birds may be a sensitive indicator of the presence of developmental toxins in the food chain in the area (Fox, Collins, and others, 1991). In the late 1970's, concerns about possible declines in Wisconsin populations of Forster's terns led to a study by Harris and Trick (1979) of the status and nesting ecology of this species. Kubiak and others (1989) found several signs of reproductive impairment (poor hatching and fledging success, nest abandonment) as well as malformations in Forster's terns nesting in the lower Fox River area that may have been related to high concentrations of PCB's and other organic contaminants. In a followup study, Harris and others (1993) found that the increase in reproductive success of Forster's terns in 1988 was associated with a marked decrease in the PCB content of the eggs. Wasting syndrome, however, was still observed in late chick development. Fox, Collins, and others (1991), in a study lasting from 1979 through 1987, found that the incidence of bill malformations, such as crossed or deflected bills, was 10 to 32 times greater in double-crested cormorants from colonies in the Fox River/Green Bay area than in reference areas away from the Great Lakes. Also found were higher numbers of malformed chicks than in all other areas examined in the Great Lakes region. The authors suggested that this high rate of malformation may be related to concentrations of PAH's and PCB's in the region. A data base on congenital defects in wild birds was created as part of the study by Fox, Collins, and others (1991). Hoffman and others (1996) provide a review of studies of the effects of PCB's and dioxins in tissues of birds, including several studies from the Green Bay area.

Health advisories have been issued for consumption of certain fish species from Wisconsin and Michigan waters of the study area. These advisories are based on concentrations of PCB's, pesticides, and mercury in fish-tissue samples collected by the States. The Fox River, East and West Twin Rivers, Manitowoc River, Sheboygan River, Milwaukee River, Pike River, Cedar Creek, and Big Green Lake have fish-consumption advisories for PCB's and pesticides. The Menominee River has an advisory for mercury and dioxins. Results of an MDNR study of caged channel catfish at the mouths of the Menominee and Escanaba Rivers, however, found no detectable PCB uptake (Taft, 1989c; Michigan Department of Natural Resources, 1994b). Mercury advisories have been issued for sport fish in numerous streams and lakes of the study area, primarily for walleye, smallmouth and largemouth bass, and northern pike. Grieb and others (1990) studied mercury concentrations in lakes in the Upper Peninsula of Michigan and found a statistically significant negative correlation between dissolved organic carbon (DOC) in the water column and mercury concentrations in fish inhabiting seepage lakes. This relation indicates that high concentrations of DOC reduce the bioavailability of mercury to aquatic biota in these lakes. These authors also determined that 99 percent of the mercury in fish muscle tissue in their study was in the form of methylmercury, the most bioavailable form of mercury.

Toxicity tests on aquatic biota of the study area confirm that contaminants are of great concern in several areas, especially in the lower Fox River and the Menominee River. Ankley, Lodge, and others (1992) found that two major factors probably contribute to water quality problems in the Lower Fox River/Green Bay area: eutrophication, which has contributed to anaerobic conditions and high ammonia concentrations in the sediments, and PCB's, which are ubiquitous in sediments and biota at significant concentrations. Ecological risk assessment has led to the identification of several stressors that significantly affect the water quality and environmental quality of the Green Bay ecosystem: wetland and shoreland filling, exotic invasions, persistent toxic organic contaminants, nutrient loading, and sediment loading (Harris and others, 1994). Hokanson and Lien (1985) found that walleye ova collected from the Fox River produced offspring with reduced post-larval (Post-Larvae I) survival in laboratory-rearing experiments when compared to walleye ova from uncontaminated sites. This finding indicates that contaminants may be affecting development of walleye in this area. Auer and Auer (1990) assessed site substrate suitability for walleye spawning in the lower Fox River. They determined that optimal sites were rare and that 75 percent of the suboptimal substrates were chemically unsuitable for development of the eggs on the basis of criteria established for acceptable concentrations of dissolved oxygen, free NH_3, or H_2S. Their data indicated that successful natural reproduction of walleyes was limited by the reduced availability of suitable substrate in the section of the Fox River from the DePere Dam to the mouth (approximately 12 kilometers of river). Fabacher and others (1991) examined the laboratory toxicity of PCB's in sediment extracts from five rivers, including the Fox and Menominee, to the Japanese medaka (*Oryzias latipes*). They found that the incidence of non-neoplastic liver abnormalities and caudal or pectoral fin erosion was significantly greater after exposure to sediment extracts from the Fox and Menominee Rivers than after exposure to experimental controls. The co-occurrence of caudal and pectoral fin erosion increased significantly after exposure to sediment extracts from the Menominee River.

SUMMARY OF BIOLOGICAL INVESTIGATIONS RELATING TO WATER QUALITY

A total of 470 biological investigations were found that relate to water quality in the Western Lake Michigan Drainages. Every effort was made to locate all investigations in the study area but no doubt some were missed. The studies of aquatic biota are summarized in four categories: (1) populations and community structure, (2) health of aquatic biota, (3) chemical concentrations in tissues, and (4) toxicity tests (tables 1 through 4). Approximately 8 percent of the studies span more than one category, so these studies are listed in more than one table. No evaluations of the quality of the research are attempted. Selected studies and programs are discussed below.

Populations and Community Structure of Aquatic Biota

Information on populations and community structure of aquatic biota can be used in conjunction with water-quality data to develop an understanding of water-quality trends and relations of aquatic biota to water quality. Populations and community structure of aquatic biota are influenced by current and historical water-quality conditions and biogeography. Community measures can provide temporally-integrated information on stream or lake characteristics and water-quality effects, whereas chemical measurements of water quality indicate conditions only at the time of sampling.

Table 1 and figures 2 and 3 summarize 356 reports on populations and community structure of aquatic biota in the study area. Most published studies were from the 1980's [96] and 1990's [178]. Published studies in the 1950's and earlier [21] were generally difficult to obtain once identified. Three publications by Marsh, on plankton and crustacea, were the only

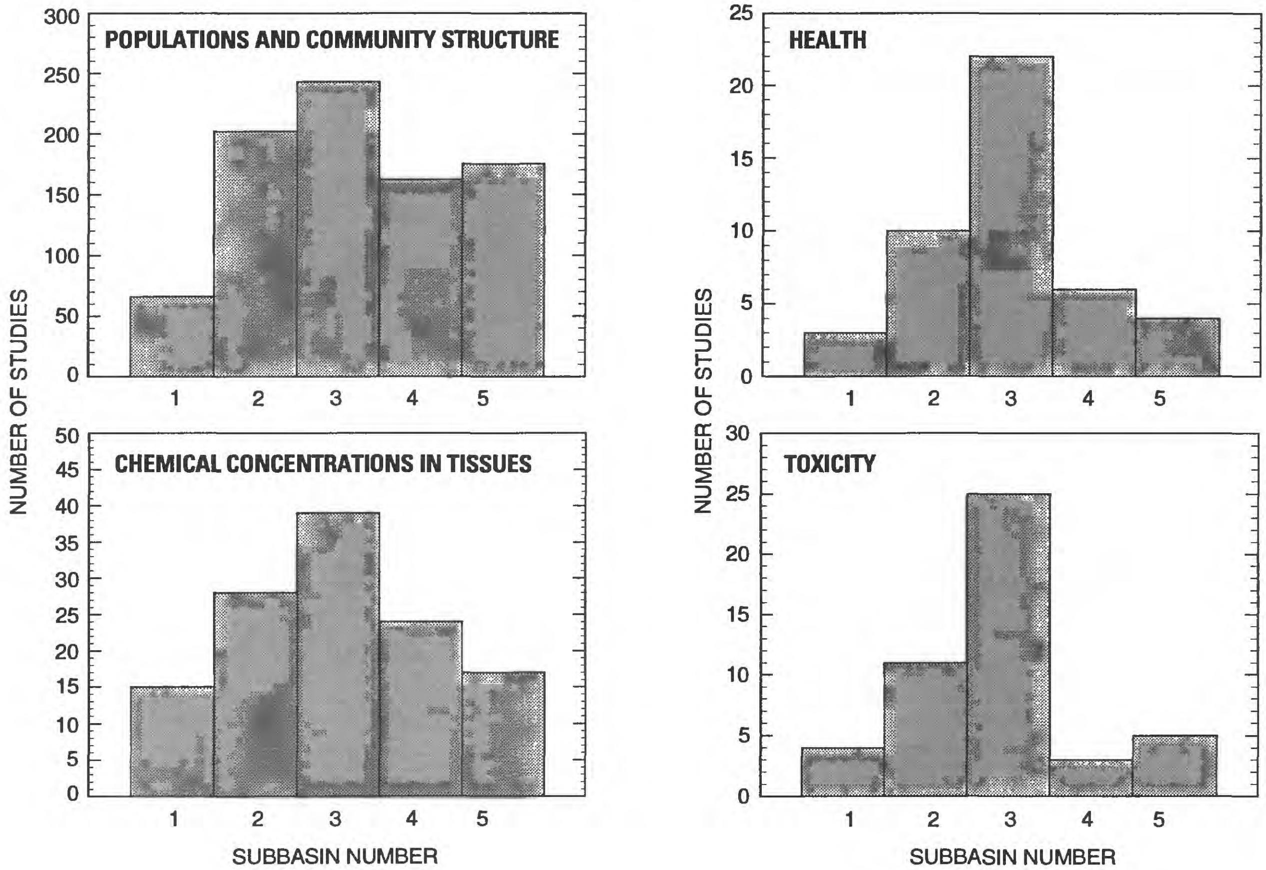

Figure 2. Number of studies according to subbasin for populations and community structure of aquatic biota, health of aquatic biota, chemical concentrations in tissues of aquatic biota, and toxicity to aquatic biota. Single studies may include more than one basin.

available published studies from around the turn of the century (Marsh 1891a, 1891b, 1903).

Numerous reports from regional studies cover most or all of the subbasins with regard to algae, macrophytes, invertebrates, amphibians and reptiles, fish, birds, wetland and flood plain vegetation, and endangered or threatened species. Numbers of studies were about equally divided among Subbasins 4 [162] and 5 [175], whereas the studies of Subbasin 3, the Fox/Wolf Subbasin, were more numerous than those of the other subbasins [243], although Subbasin 2 also was commonly studied [202]. Subbasin 1 had the fewest number of studies [66]. Studies were more regional [224] than local [134] in scale.

Most studies dealt with one type of biota. Fish and aquatic insects were the most commonly studied organisms; 124 studies of fish and 109 studies of invertebrates. Invertebrates studied were generally aquatic insects. Wetland and flood plain vegetation [64], birds [56], and amphibians and reptiles [54] were the next most frequently used biota in studies of populations and community structure, followed by endangered species [42] and macrophytes [40]. Published studies on communities of algae [27] were few.

Algae. Research on algae in the study area has focused mostly on species abundance in relation to eutrophication of lakes. Many phytoplankton studies have been done, including several in the Winnebago Pool lakes (Marsh, 1903; Rickett, 1924; Juday, 1943). Extensive work on phytoplankton populations along the water-quality gradient between the lower Fox River and Green Bay have been conducted from the 1980's to present by Paul Sager and coworkers (Richman and others, 1984; Sager and others, 1984, 1988; Richman and Sager, 1990; Sager and Richman, 1991; Rhew, 1992). Smith (1920, 1924) describes an extensive study

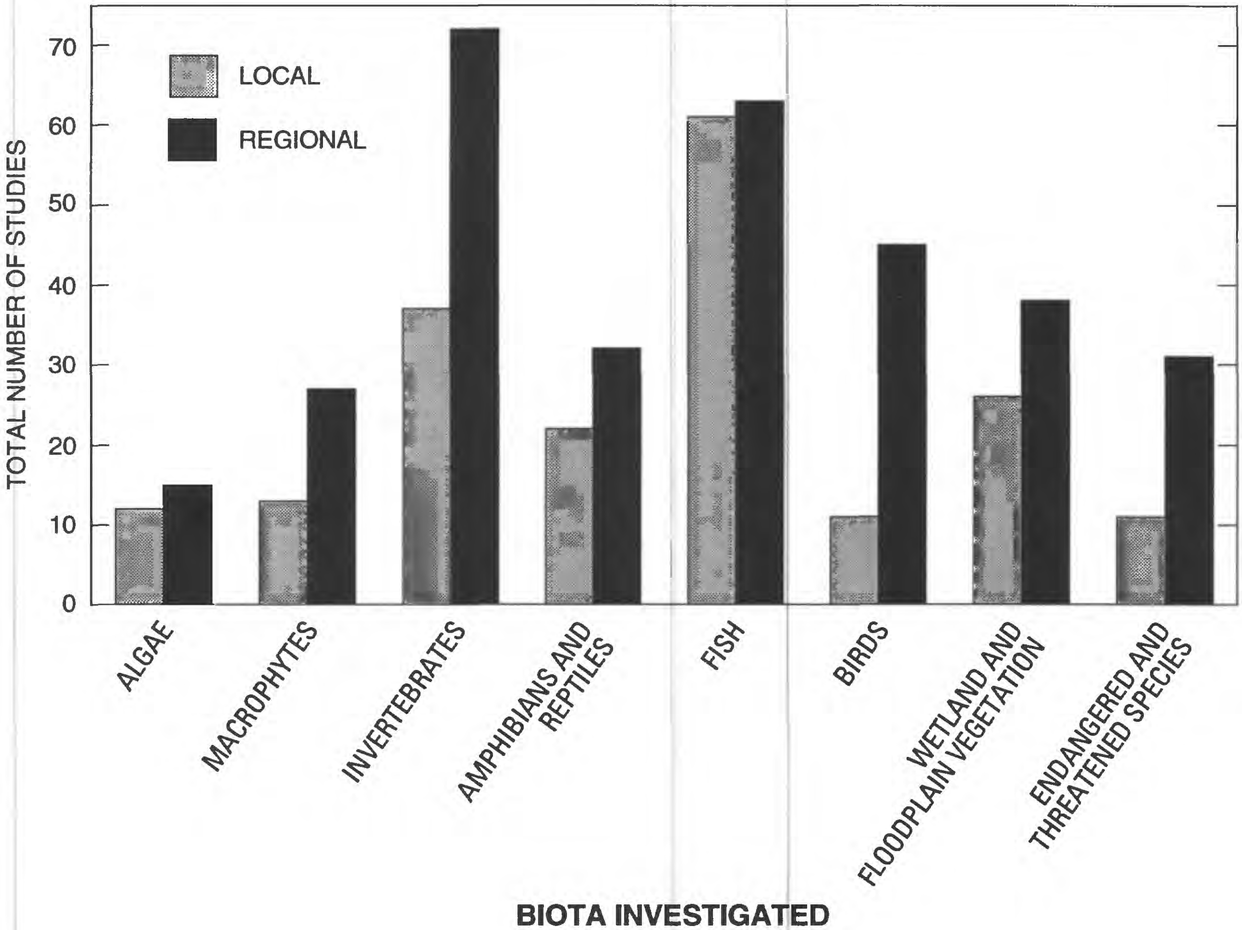

Figure 3. Number of studies of populations and community structure of aquatic biota from the Western Lake Michigan Drainages study area according to spatial scale, all subbasins.

of the phytoplankton of the inland lakes of Wisconsin. Prescott (1962) provides an extensive key to the algal species of the Great Lakes area except for the desmids and diatoms, for which he gives an illustrated key to the genera. The USGS collected data on phytoplankton species and abundances for its National Stream-Quality Accounting Network (NASQAN) from 1974 through 1981 at sites on the Menominee River, Fox River, Manitowoc River, Milwaukee River, and Cedar Lake. Determination of populations and community structure of periphyton in streams and rivers of the study area is currently being done as part of the NAWQA Program (Gurtz, 1994).

Macrophytes. Research on macrophytes in the study area has been oriented primarily toward lakes, probably because of concerns with abundant growths of various macrophytes in many Wisconsin lakes (for example, see Sabol, 1983). A Wisconsin Lake Plant Database, developed by Nichols and Martin (1990), contains information from historical and recent surveys and a large bibliography on macrophyte studies in Wisconsin. The data base is managed by the WDNR for use in research and management. The MDNR includes surveys of macrophyte communities to assess streamwater quality, especially for water-quality problem evaluations, identification of point- and nonpoint-source contamination, and NPDES permits (Michigan Department of Natural Resources, 1994b).

Aquatic Invertebrates. Aquatic-invertebrate research in the study area has focused primarily on insects, although the importance of other groups has not been overlooked. Species abundances and distributions of aquatic insects are described in detail by Hilsenhoff (1975, 1981). A large aquatic invertebrate data base representing 1984 to the present is housed at the University of Wisconsin-Stevens Point, College of Natural Resources (Szczytko, 1989). The data base, which is updated and populated primarily with data collected by the WDNR, is used for watershed monitoring and assessment of agricultural Best Management Practices. Data collection for the data base is done in a rapid-assessment style similar to the Rapid Bioassessment Protocols of the USEPA (Plafkin and others, 1989) and is designed for quick retrieval of information on abundance and distribution of the invertebrate populations (Wisconsin Department of Natural Resources, 1994). The data base also includes qualitative estimates of habitat and water quality (Szczytko, 1989). The MDNR uses invertebrate biotic-index values in water-quality assessments and reports some of this information in their water-quality assessment reports to Congress (Michigan Department of Natural Resources, 1990, 1994b). Determination of populations and community structure of aquatic invertebrates in streams of the study area is currently being done as part of the NAWQA Program (Cuffney and others, 1993).

Mollusk research in the study area has historically involved censuses of a diverse array of native mussels and, more recently, potential threats to their populations such as from the introduced zebra mussel. The Milwaukee Public Museum has an extensive collection of mollusk specimens collected from Wisconsin and elsewhere since the late 1800's. The museum also maintains a data base of the collection. The collection includes approximately 18,000 mollusk specimens from Wisconsin (Jass, 1995). Mathiak (1979) did an extensive survey of the unionid mussels of Wisconsin from 1973 to 1977. The Wisconsin Zebra Mussel Watch project of the University of Wisconsin Sea Grant Institute began in 1990. The project is designed to determine zebra mussel presence and rate of colonization in Wisconsin, distribute information to the public, and develop and test methods for zebra mussel detection in early-life stages of development (University of Wisconsin Sea Grant Institute, 1996). The Michigan Sea Grant Program has a similar mission with regard to zebra mussels as part of the Great Lakes Sea Grant Network (Michigan Sea Grant Program, Ann Arbor, Mich., written commun., 1995). The University of Michigan maintains a list of Michigan molluscan fauna detailing their distribution and rare and endangered status in Michigan (Detwiler and others, 1991). The National Oceanographic and Atmospheric Administration (NOAA) has conducted the Mussel Watch program since 1984 and has sites in Green Bay and Milwaukee Bay (Turgeon and Robertson, 1995).

Amphibians and Reptiles. Historical reports of amphibians and reptiles focused on identifying new species and determining the distribution of these organisms. More recent reports have emphasized the effects of water quality on these organisms. These studies include regional and selected watershed surveys that identify community structure and function and changes in populations with time. Some extensive surveys in the study area include a long-term frog and toad monitoring program, an endangered species watch, and a regional community profile. Frog and toad surveys started in 1984 as a volunteer program coordinated by the WDNR and became a long-term monitoring program (Mossman and Hine, 1985). The Milwaukee Public Museum became a cooperator in the project in 1986 (Casper, 1987a), and it has developed a data base and published reports with the following objectives: (1) to determine the distribution of all amphibians and reptiles in Wisconsin, (2) to assess abundance and population trends, and (3) to identify research, conservation, and management needs. Results of later frog and toad surveys have been published in reports from both institutions (Mossman and others, 1991; Casper, 1996). Casper (1995) describes the progress of the Wisconsin Herpetological Atlas Project of the Milwaukee Public Museum. The MDNR will begin a statewide frog and toad survey in 1996 (Michigan Department of Natural Resources, 1995). Other notable publications include a bibliography of herpetological research in Wisconsin by Dlutkowski and others (1987) and its update (Watermolen, 1992c), a book on the geographic distributions of the amphibians and reptiles of Wisconsin (Casper, 1996), and a series of three field guides on Michigan amphibians and reptiles (Harding and Holman, 1990, 1992; Holman and others, 1993).

Fish. Extensive research has been done on populations and community structure of fishes in the study area. Hubbs and Lagler (1941) compiled a detailed accounting of fishes in the Great Lakes region. Becker (1983) presents a comprehensive compilation of fishes found in Wisconsin by various collectors; information is also provided on identification of fish as well as their known distribution, status, habitat, and biology. A statewide survey of fish communities of the inland waters of Wisconsin was begun in 1974 by the Bureau of Research, WDNR (Fago, 1992). Surveys of the Root, Milwaukee, Sheboygan, Manitowoc, and Twin River Basins in the study area are complete, and most of the surveys in other subbasins in the study area are partially completed. Several local studies have been done, concentrating on one stream or watershed. Some are referenced herein, but many are no doubt unpublished. In particular, fish managers from the WDNR and MDNR generally do not publish results of routine data-collection efforts; these data are usually available in paper copy upon request. Results of MDNR invertebrate and fish-community surveys for water bodies that do not meet Federal Clean Water Act guidelines, termed "non-attainment" waterbodies, are published in the Michigan water-quality assessment report to Congress (Michigan Department of Natural Resources, 1994b).

Birds. The population status of several birds is of concern in the Great Lakes region, and research in the study area has generally focused on endangered and threatened species. Gromme (1963) and Granlund and others (1994) describe the birds of Wisconsin and Michigan, respectively. Benyus and others (1992) give an extensive listing of birds and their habitats in the upper part of the study area in the Nicolet and Hiawatha National Forests. The Wisconsin results of the U.S. Fish and Wildlife Service (USFWS) Breeding Bird Survey[2] were published as 5-, 10-, and 15-year summaries (Robbins, 1971, 1977, 1982). Temple and Cary (1987) published results of the Wisconsin Checklist Project, a 5-year program (1982–1986) that used weekly bird counts from volunteer observers. The Wisconsin Society for Ornithology also does an annual Christmas Bird Count (Hilsenhoff, 1995). In addition, a Wisconsin Breeding Bird Atlas was started in 1995 as a joint project between the Wisconsin Society for Ornithology, the WDNR, The Nature Conservancy, and the USFWS (Ken Stromborg, U.S. Fish and Wildlife Service, Green Bay, Wis., oral commun., 1995; Weise and others, 1995). The MDNR has a cooperative program with the USFS and USFWS to inventory populations of nesting bald eagles statewide each year. The surveys began in the 1960's (T. Weise, Michigan Department of Natural Resources, Natural Heritage Division, Lansing, Mich., written commun., 1994). The WDNR and MDNR also have programs to inventory populations of the common loon and other nongame species in their States.

Wetland Vegetation. Wetland vegetation has also been the subject of past and ongoing research in the study area. The Wisconsin Wetland Inventory completed its initial survey of the State's wetland in 1985. The digital update of this survey is due to be completed in 1996. Curtis (1971), Eggers and Reed (1987), and Reed (1988) reported on regional studies that characterize, list, and illustrate wetland vegetation of the study area. In the south, the University of Wisconsin-Milwaukee (UWM) Field Station has produced an extensive body of research on taxonomy, wetland vegetation, and wetland restoration at Ozaukee County sites; namely, the Cedarburg and Sapa Bogs (Grittinger, 1971; Kroeger, 1986; Kline, 1990a, 1990b, 1991; Reinartz, 1990, 1994; Reinartz and Warne, 1990, 1993; Bowers and Kline, 1991; Redmond and others, 1993; Yencha, 1993; Leithoff, 1994; Thompson, 1995). In the north, research has focused on evaluating the extent of wetland loss and characterizing wetland vegetation along the shores of Green Bay and the Door Peninsula (Harris and others, 1977; Bosley, 1978; Keough, 1986). Yencha (1993) described the fauna and vegetation of recently restored wetland in the Green Bay area and Manitowoc. Comparably few studies have been done on inland wetland in the north.

Endangered and Threatened Aquatic Biota. Wisconsin and Michigan have natural heritage programs for conservation of species and biodiversity. The Bureau of Endangered Resources of the WDNR established the Natural Heritage Inventory Program in 1985 in order to (1) identify rare or unique plants, animals, and communities, (2) determine their endangered status and ranking, and (3) map their distributions. The computerized inventory system was established in cooperation with The Nature Conservancy and is compiled from several sources. The WDNR is able to provide electronic copies of such data to its users, and this data also is available in a Geographic Information System (GIS) format. An endangered-species report by Brynildson (1980) describes endangered species of fish, mollusks, and reptiles and their habitats in the Wisconsin part of the study area, with a goal of increasing awareness of endangered biota in the state. The MDNR's Wildlife Division has a Natural Heritage Program that was established in 1983 to locate, protect and restore native plants and animals, natural areas, and other natural features. This program's data base is also computerized as the Michigan Natural Features Inventory (MNFI) Biological Conservation Database (Michigan Department of Natural Resources, Natural Heritage Program, Endangered Species Office, Lan-

[2]The Breeding Bird Survey is now managed by the Biological Resources Divison of the U.S. Geological Survey (LaRoe and others, 1995; Thomas A. Muir, U.S. Geological Survey, Reston, Va., personal commun., 1996).

sing, Mich., written communication, 1992, 1993; Herman, 1994). Benyus and others (1992) did a regional study on endangered species of wildlife in the Upper Great Lakes region in parts of Minnesota, Wisconsin, and Michigan (see also Benyus, 1989). Their report contains wildlife-habitat trend information on about 389 species of amphibians, reptiles, birds, and mammals with their associated habitats and describes a data base, called NORTHWOODS, that includes the information. The report and data base were designed to be used by land managers when making land-use decisions that affect the region's wildlife; and the data base is maintained by and available from the USDA Forest Service–North Central Forest Experiment Station in St. Paul, Minn.

Combined Biota. Studies by state and Federal agencies that combine investigations of several types of biotic communities in water-quality assessments of the study area include those by the WDNR, MDNR, MDEQ, USFWS, and USGS, as well as the USDA Forest Service, Federal Energy Regulatory Commission (FERC), and Department of Defense. For example, the MDNR Great Lakes and Environmental Assessment Section (GLEAS) of the Surface Water Quality Section developed a series of protocols to address the increasing demand for a more rigorous and standardized evaluation of nonpoint-source effects on water quality. GLEAS protocols were developed for assessment of stream habitat and invertebrate and fish communities (Michigan Department of Natural Resources, 1991a).

The USDA Forest Service is developing aquatic ecological classification units for national forests including the Nicolet National Forest in Wisconsin (Maxwell and others, 1995). The classification units are being developed to assess the current ecological status and potential of stream reaches, identify natural disturbance patterns, and develop and monitor forest-management strategies. Data-collection efforts in the Nicolet National Forest have included information on habitat characteristics, water quality, and abundance and distribution of fish, mollusks, and macroinvertebrates (Dale Higgins, USDA Forest Service, Rhinelander, Wis., written commun., 1994; Sue Reinecke, USDA Forest Service, Park Falls, Wis., written commun., 1996).

Construction and relicensing of hydroelectric projects that are regulated by FERC require an evaluation of the potential environmental impacts of the project (Mecozzi and others, 1991). Data are collected on water quality, fish and wildlife habitat, and other river resources such as communities of macrophytes, invertebrates, amphibians, fish, and birds. The data are available from FERC for many hydroelectric projects as published draft and final environmental impact statements (see Federal Energy Regulatory Commission, 1995). Licenses may be granted for up to 50 years for projects, and many of the 23 FERC-regulated dams in the Wisconsin part of the study unit are currently being relicensed.

Michigan State University researchers have collected 13 years (1983 to present) of algal, invertebrate, and fish data on the Ford River of Michigan's Upper Peninsula to monitor the effects of low-level, long-term electromagnetic radiation from the U.S. Navy's Extremely Low Frequency (ELF) submarine communication system (Burton and others, 1991).

The Marsh Monitoring Program is a cooperative project between the Long Point Bird Observatory, Environment Canada, and the U.S. Great Lakes Protection Fund. It is designed to assess marsh health in the Great Lakes region by monitoring species abundances of marsh birds and amphibians during the breeding season. Sites are primarily at the Great Lakes Areas of Concern (Chabot, 1996).

Health of Aquatic Biota

Studies of the health of aquatic biota can be highly informative from a water-quality standpoint because they measure the overall response of individuals to their environment. Effects of contaminants on the health of aquatic biota may range from sublethal chronic effects over a period of months to years to acute effects within minutes to weeks. These effects may be observed at varying levels of contaminants, depending on a complex interaction of environmental and biological factors. Some contaminant-induced health effects can be evaluated visually, thus minimally disturbing endangered or threatened species. The disadvantage of these visual evaluations is that relating the observed effects to specific contaminants is generally difficult. Single or multiple contaminants may produce a combination of behavioral, morphological, physiological, and reproductive effects. Minor responses at the individual level may manifest themselves at the population level as major threats to species survival (Rand and Petrocelli, 1985).

Only 30 studies were located that dealt with health of aquatic biota in the study area (table 2 and fig. 2). With the exception of Amin and others (1973), all studies of the health of aquatic biota in the Western Lake Michigan Drainages were from the 1980's [10] and 1990's [19]. The Fox/Wolf Subbasin, especially along the lower Fox River near Green Bay, was the most commonly studied subbasin and was included in 22 of 30 studies [Subbasin 1 = 3 studies; Subbasin 2 = 10 studies; Subbasin 4 = 6 studies; Subbasin 5 = 4 studies]. Half of the studies were regional in scale [regional, 15; local, 15] (fig. 4a).

Only three studies examined the health of more than one type of biota (Wisconsin Department of Natural Resources and Michigan Department of Natural Resources, 1990; Ankley, Lodge, and others, 1992; Wisconsin Department of Natural Resources, 1993b). Most studies of the health of aquatic biota examined birds [21] or fish [9]. Birds and fish have been shown to be extremely sensitive monitors of environmental degradation, and research has recorded a variety of sublethal effects. The use of amphibians and reptiles as water-quality monitors is just starting to be explored more extensively and only two studies were found. (Hine and others, 1981; Jung and others, 1996). Two studies of invertebrate health also were found (Klemm, 1991; Ankley, Lodge, and others, 1992).

The most studied health effects on aquatic biota are reproductive impairment [21] and malformations [13] (fig. 4b). Many studies focus on one or two types of effects (for example see Harris, 1988; Custer and others, 1995); however, Ankley, Lodge, and others (1992) reported on lesions and tumors in addition to malformations and reproductive impairment in birds and fish from the Lower Fox River/Green Bay area. The WDNR (1993b) and WDNR and MDNR (1990) examined tumors in fish in addition to two other effects. Tumors and liver lesions are sometimes a result of exposure to carcinogenic or mutagenic contaminants but these effects are not commonly examined in reports found. The "other" category [9] included effects such as feeding success, parasitism, and physiological-stress measures. The incidence of parasites in fish may increase as a result of contaminant-related stress; this possibility was investigated by Amin and others (1973) in fish from the Root River near Milwaukee. A study by Rattner and others (1993) of cytochrome P450 activity and associated proteins in embryos of black-crowned night herons from the Fox River/Green Bay area indicates that this physiological indicator of health may be useful in assessment of PCB exposure.

Chemical Concentrations in Tissues of Aquatic Biota

Numerous water-quality issues can be addressed by knowing the concentration of contaminants in the tissues of aquatic organisms. For example, human health risks associated with the consumption of wildlife may be evaluated. Interpretation of the concentration of a specific contaminant in tissues of an organism is needed to assess the significance of the contaminant concentration to the health of that aquatic organism. Concentrations may be compared to various organism health characteristics and to levels found by prior research to be harmful. The bioavailability of contaminants to biota is a function of the contaminant concentration in the environment and other physical, chemical and biological processes. The uptake of contaminants by biota may involve: (1) direct absorption from the water, (2) assimilation through food, sediment and detritus and (3) adsorption into the outside of the organism with or without subsequent absorption. The study of the concentration of contaminants in tissues ultimately helps researchers to better understand the transport and fate of contaminants in ecosystems.

Out of a total of 69 studies on chemical concentrations in tissues of aquatic biota, only 3 were found that were done before 1980 (table 3 and fig. 5). The relative recency of the studies may reflect the literature-search methods or perhaps a lack of well-developed laboratory methods before that time.The Fox/Wolf Subbasin was the most common subbasin location of the studies [39], and the mouth of the Fox River in Green Bay was the most common location within the subbasin [Subbasin 1 = 15 studies; Subbasin 2 = 28 studies; Subbasin 4 = 24 studies; Subbasin 5 = 17] (fig. 2). Studies were more regional than local in scale [regional, 42; local, 27], particularly for fishes.

Ten studies examined more than one type of biota. Fish were the dominant organism analyzed for chemical concentrations in the tissues [50 studies]; 20 studies analyzed birds. Only 13 studies were identified that analyzed invertebrate tissues for contaminants. Two studies examined amphibians or aquatic-associated reptiles. Tissues of various species of macrophytes have been used in several water-quality studies outside the study area because of the ability of macrophytes to

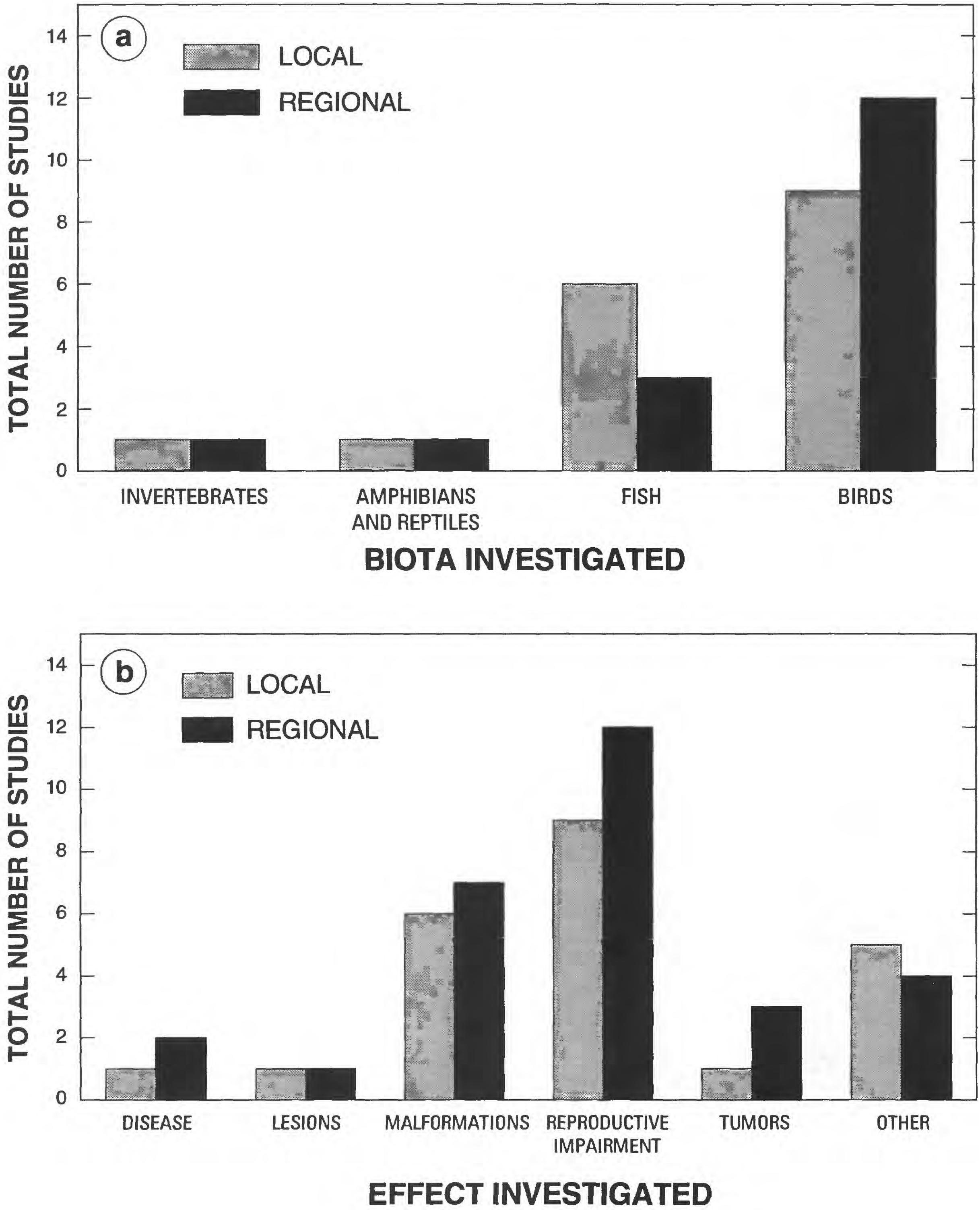

Figure 4. Number of studies of the health of aquatic biota from the Western Lake Michigan Drainages study area according to spatial scale, all subbasins.

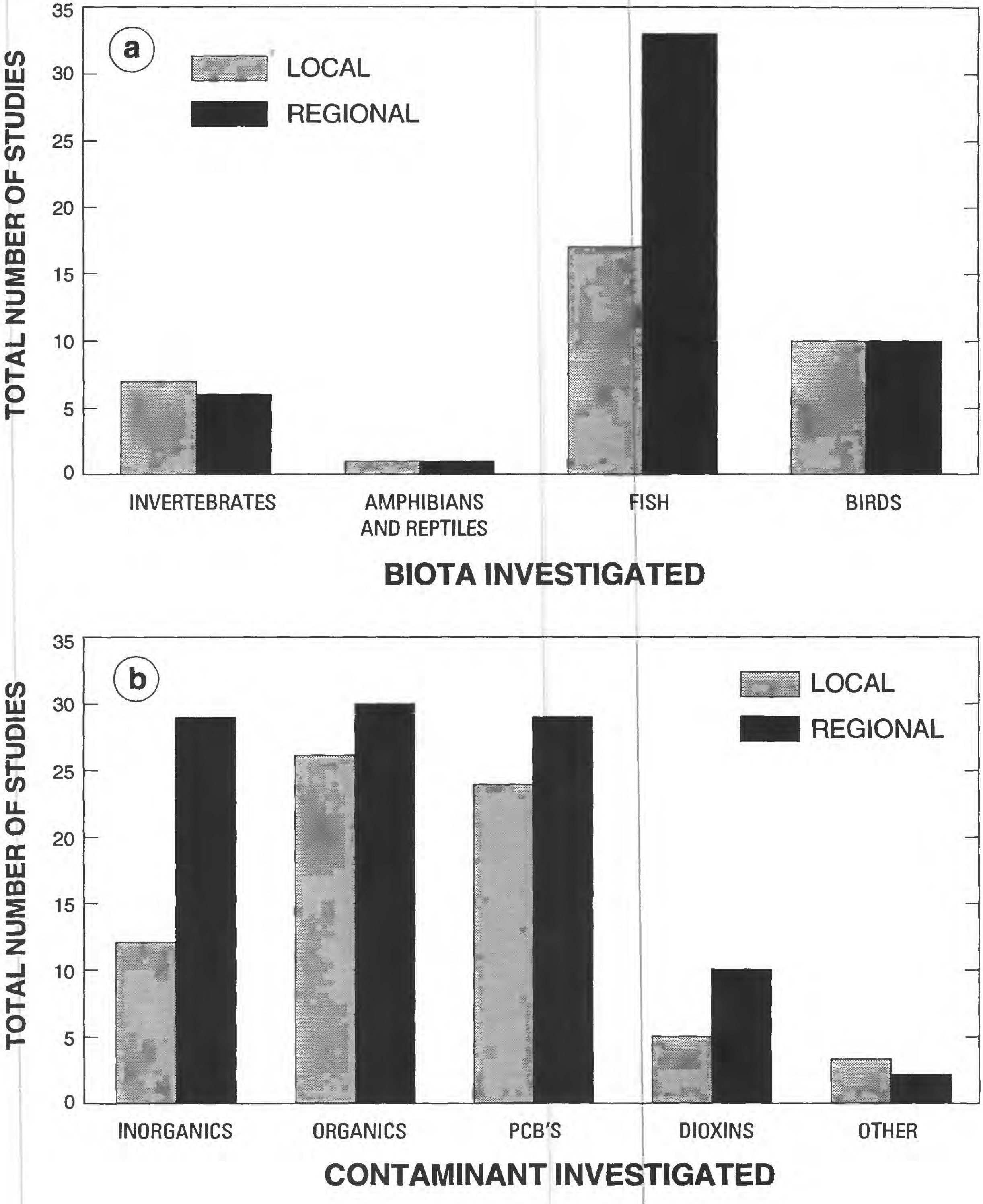

Figure 5. Number of studies of chemical concentrations in tissues of aquatic biota from the Western Lake Michigan Drainages study area according to spatial scale, all subbasins.

accumulate many inorganic and some organic contaminants; however, no published reports were found on macrophyte-tissue work in the study area. The Western Lake Michigan Drainages study unit of the NAWQA program is analyzing tissues of macrophytes for trace elements, but reports have not yet been published.

Organic contaminants were more commonly investigated than were inorganic contaminants [organic, 56; inorganic, 41]. Approximately half of the studies of organics were regional and half were local, whereas studies of inorganics tended to be more regional. The primary organic contaminants studied have been PCB's. Few dioxin-related studies were located [15], despite the presence of dioxins in several urban areas as indicated by available water or sediment data. The high expense of dioxin analyses may be a deterrent to their inclusion in many studies. Some studies used "dioxin equivalents" to estimate dioxin concentrations in tissues and were included in the dioxin category (for example, see Tillitt and others, 1993). At present, the USEPA, WDNR, MDNR, and MDEQ are the major sources of data on concentrations of dioxins in biota from the study area (Michigan Department of Natural Resources, 1991b; U.S. Environmental Protection Agency, 1992a and b; Wisconsin Department of Natural Resources, 1994; Michigan Department of Environmental Quality, 1995).

Most tissue-contaminant research in the study area has been done by Federal and state agencies or has been agency sponsored. Several programs are studying the long-term fate and transport of pollutants through the food chain of the Great Lakes. The USEPA Guidance for State Water Monitoring and Wasteload Allocation Programs (1985) recommends that all states analyze fish and other tissue to detect potential human-health or environmental problems. The WDNR and MDNR/MDEQ analyze fish for contaminants, as do the USEPA, USFWS, and USGS.

The WDNR does tissue-contaminant studies on various wildlife associated with aquatic systems, including sport fish, waterfowl, turtles, and aquatic mammals.The WDNR operates a fish-tissue monitoring program that processes and analyzes an average of 1,500 samples per year on a statewide basis. Samples from inland lakes and streams, as well as the Great Lakes, are analyzed for substances including PCB's, mercury, chlorinated pesticides, and other metals and priority pollutants. Eagles and loons are monitored as sentinel species for contaminants. The WDNR issues fish- and waterfowl-consumption advisories when contaminant concentrations in tissues are found to exceed levels of concern (Wisconsin Department of Natural Resources, 1994). In addition, tissue monitoring is used to assess the effects of point and nonpoint sources of pollution, as well as the effects of contaminated sediments. Most WDNR sampling efforts are concentrated in areas where contamination problems are most likely. The criteria used for site selection include sites of industrial discharge or other suspected sources of contamination, areas of nonpoint-source loadings, lakes with large game-fish populations, and water bodies used by large numbers of anglers (Wisconsin Department of Natural Resources, 1992).

The MDNR and MDEQ cooperatively run the Fish Contaminant Monitoring Program (FCMP) to monitor the concentrations of mercury and selected industrial chemicals and synthetic organic contaminants in fish in Michigan (MDNR, 1991a, 1994a; Taft, 1991d; MDEQ, 1995). The program began in 1986. The data are used by MDEQ managers and others to (1) identify trends in surface-water quality with respect to persistent, bioaccumulative chemicals, (2) determine whether fish-contamination problems exist in specific surface waters, (3) evaluate the effectiveness of pollution-control programs, and (4) provide data for the establishment or removal of fish-consumption advisories. The FCMP is designed to test contaminant concentrations against current fish-consumption advisory levels that the Michigan Department of Public Health has defined for eight chemicals: chlordane, DDT, dieldrin, heptachlor, mercury, mirex, PCB, and toxaphene. Many monitoring sites have been established on inland lakes; only a few sites are within the study area and these are concentrated mostly on the Escanaba, Menominee, and Michigamme Rivers (Michigan Department of Natural Resources, 1991b, 1994a).

The USEPA National Study of Chemical Residues in Fish (NSCRF) began in 1986 as an outgrowth of the USEPA National Dioxin Study (U.S. Environmental Protection Agency, 1992a and b). The concern that fish were bioaccumulating toxic contaminants in addition to dioxins was the primary reason for initiating the NSCRF. Tissue samples collected as part of the NSCRF are analyzed for dioxins and furans, PCBs, pesticides, mercury, biphenyl, and other organic compounds. Nine monitoring sites are in the study area; they include sites on the Upper Fox River, the lower Fox River, near the mouths of the Manitowoc, Milwaukee, and Sheboygan Rivers, and in the Peshtigo River harbor.

In 1964, the USFWS began a program called the National Pesticide Monitoring Program. This program was expanded to monitor concentrations of organochlorine pesticides, industrial chemicals, and trace elements in fish and wildlife. It was renamed the National Contaminant Biomonitoring Program (NCBP) (Jacknow and others, 1986). The NCBP had only one site near the study area, which was in Lake Michigan at Sheboygan, Wisconsin. The NCBP ended in the mid-1980's. Data from this program are available in several publications (May and McKinney, 1981; Schmitt and others, 1981, 1983, 1985, 1990; Schmitt, 1990; Schmitt and Brumbaugh, 1990).

The USGS began sampling tissues of biota in the study area in 1992 as part of its nationwide NAWQA program (Crawford and Luoma, 1993; Gurtz, 1994; Gilliom and others, 1995). Aquatic biota and fine streambed sediments were sampled from 18 sites in 1992, 8 sites in 1994, and 6 sites in 1995 for determination of inorganic contaminants, specifically trace elements. Biota sampled consisted primarily of whole caddisfly larvae (Family Hydropsychidae) but other insects, fish, and macrophytes also have been collected. Samples were collected and analyzed for a suite of organic contaminants at 18 sites in 1992 and at 6 sites in 1995 . Whole fish, primarily white sucker (*Catostomus commersoni*), were collected for determination of organic contaminants. Data are currently available in computerized form, and preliminary results are given in Scudder and others (1995) and in the newsletter of the Western Lake Michigan Drainage study unit (U.S. Geological Survey, 1995). A cooperative effort between the USGS NAWQA program and the National Biological Service (NBS) surveyed carp from two streams of the study area for effects of endocrine-disrupting contaminants (U.S. Geological Survey, 1995).

Toxicity to Aquatic Biota

The toxicity of a contaminant to an organism is related to contaminant concentration, the duration of exposure, and other environmental and biological (life history) factors that may act synergistically or antagonistically. Toxicity tests are often done in the laboratory with single contaminants and single species, although methods for laboratory tests using multiple contaminant exposure are becoming more established. Laboratory testing allows for standardized, reproducible conditions by minimizing the number of confounding factors. Field-based toxicity tests have the advantage of producing results that are potentially more comparable to real-world conditions, but results may be difficult to interpret because of uncontrollable variables. Toxicity tests may be acute or chronic. Acute toxicity tests measure severe, short-term responses, such as survival or mortality. Lethal and (or) sublethal responses produced by repeated or long-term exposure to contaminants are generally measured by chronic toxicity tests. Changes in behavior (for example, swimming), physiology (for example, growth, reproduction, and development), biochemistry (for example, enzyme levels), and histology (for example, liver lesions) are commonly used to measure chronic toxicity (Rand and Petrocelli, 1985).

Only 34 publications on toxicity to aquatic biota were located from the study area. More publications were from the 1990's [24] than the 1980's [10] (table 4 and fig. 6), and none were found before 1980. As was suggested for studies of chemical concentrations in tissues, the lack of studies before 1980 may be related to the state of the science, in that the field of aquatic toxicology is relatively new. Although toxicity testing on aquatic biota has been done nationwide since World War II, the greatest increase in method development has been since the late 1960's. Nationwide standards for laboratory toxicity testing were not established until 1975 (Committee on Methods for Acute Toxicity Tests with Aquatic Organisms, 1975; Parrish, 1985; Rand and Petrocelli, 1985).

Most toxicity studies are local in scale [20], and all subbasins are represented (fig. 2). Most studies, however, have been done in the Fox Wolf Subbasin [25]. Subbasin 2 is the next most frequently studied [Subbasin 1 = 4 studies; Subbasin 2 = 11 studies; Subbasin 4 = 3 studies; Subbasin 5 = 5 studies].

Fish [20] and invertebrates [15] are the most commonly examined organisms in studies of toxicity to aquatic biota in the study area. Established test species that were used in these studies primarily included the fathead minnow (*Pimephales promelas*) and the water flea (*Daphnia magna* and *Ceriodaphnia dubia). Ten studies of birds were located. Few studies of algae [3] were located, and two toxicity studies of amphibians and reptiles were found. No studies of macrophytes were located.

Use of multiple-species tests recognizes that various types of organisms in an ecosystem may respond differently to environmental stressors. Twelve studies combined toxicity tests of fish with one or more other organisms, generally invertebrates. Ankley and others

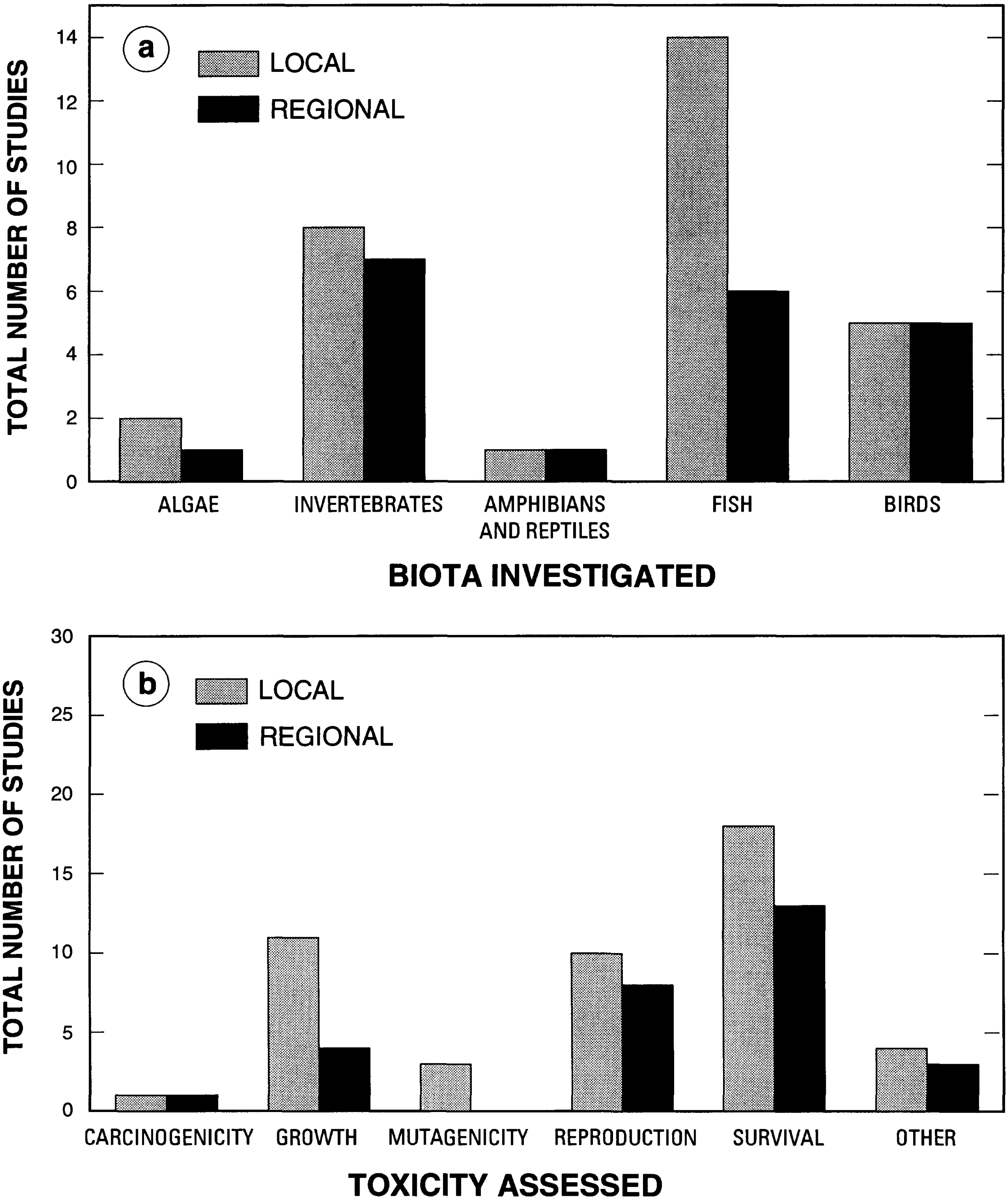

Figure 6. Number of studies of toxicity to aquatic biota from the Western Lake Michigan Drainages study area according to spatial scale, all subbasins.

(1990) did laboratory toxicity tests with sediment pore water from the lower Fox River near the mouth and DePere Dam and from the East River. Sediment pore water induced acute or chronic responses in three of four established test species of algae, invertebrates, and fish; however, no toxicity was observed for the bacteria tested. Toxic responses were similar for the invertebrate and fish, and toxicity-identification techniques indicated that these biota were responding primarily to high ammonia concentrations. The work by Ankley, Lodge, and others (1992) was a summary of several combined research efforts on algae, bacteria, invertebrates, fish, birds, and toxicity tests from the Lower Fox River/Green Bay area. This integrated approach was designed to address the total ecosystem by considering the microbial, benthic, and pelagic communities affected by sediment contamination more adequately than single-species testing could have done.

Michigan and Wisconsin both use toxicity tests in their water-quality asssessments. The MDNR/MDEQ periodically uses caged channel catfish (*Ictalurus punctatus*) at 19 Great Lakes tributary sites, including two sites in the Upper Peninsula part of the study area (Michigan Department of Natural Resources, 1994b). The Aquatic Toxicity Testing Program of the MDNR was established for compliance biomonitoring of discharges, and this program uses laboratory/field and acute/chronic toxicity tests with invertebrates and fish. Toxicity tests involving sediment are not currently part of their assessment program. The WDNR uses acute/chronic toxicity tests with invertebrates and fish for monitoring of discharges and sediment quality, and caged fathead minnows (*Pimephales promelas*) are used for field tests of bioaccumulation (Campbell and Talbot, 1993; Wisconsin Department of Natural Resources, 1994).

Slightly more studies used laboratory tests alone [12] than field tests alone [7]; and in 15 studies, laboratory and field tests were both used. Virtually all [31] toxicity studies assessed survival (fig. 6b). Effects on growth [15] and reproduction [18] also were commonly measured. Few studies examined carcinogenicity [2] or mutagenicity [3]. The "other" category [7] included various types of physiological markers. For example, Tillitt and others (1993) used a rat hepatoma cell bioassay to determine tetrachlorodibenzo-p-dioxin equivalents (TCDD-EQ) in Forster's tern eggs from Green Bay and Lake Poygan. Enzyme, DNA, RNA, and protein concentrations in livers were used by Hoffman and others (1993) as biomarkers of contaminant effects in embryos and chicks from Green Bay colonies of common terns and black-crowned night herons (*Nycticorax nycticorax*). Eight studies measured three or more toxic effects and investigated growth, survival, reproduction, and one or more other effects (Balcer and others, 1986; Lien and others, 1986; Hoffman and others, 1987; Ankley and others, 1990, Ankley, Lodge, and others, 1992; Ingersoll and others, 1991; Hoffman and others, 1993; Michigan Department of Natural Resources, 1994b).

CONCLUSIONS

Our examination and categorization of 470 studies of aquatic biota indicate that most biological studies that relate to water quality in the study area focus on populations or community structure [356]. The next most common topic is chemical concentrations in tissues of aquatic biota [69]. Overall, most of the publications that we located are from the 1980's and 1990's, and about half the studies are regional and half are local. Fish and invertebrates generally are the primary study organisms, although birds were the dominant organism in studies of the health of aquatic biota.

Our findings indicate that the health of all types of aquatic biota in the study area—especially amphibians, aquatic-associated reptiles, and invertebrates—is the least studied of the major categories of investigation. Few studies have been done on populations and communities of algae (especially periphyton in streams). Toxicity studies were rarely done using water, sediment, or biota from subbasins other than the Fox/Wolf Subbasin, and algae and amphibians/reptiles were rarely examined in the toxicity studies that were done. Sublethal effects such as carcinogenicity, mutagenicity and other physiological changes have generally not been addressed. The Fox/Wolf Subbasin has been the focus of far more studies than the other four subbasins, most likely because of the extent and severity of water-quality problems in the Lower Fox River/Green Bay area and because it is the largest subbasin. Studies in the other subbasins are needed if the water quality of these areas is also to be adequately assessed.

The adequacy of the studies for determining spatial or temporal trends with respect to length of studies or data comparability among studies was not examined in this summary. This summary provides retrospective data for the Western Lake Michigan Drainages NAWQA program of the U.S. Geological Survey. The

NAWQA program was designed to provide a longterm (decades) data set for populations and community structure of aquatic biota and chemical concentrations in tissues of aquatic biota using methods that are nationally consistent.

Aquatic biota from many of the rivers, lakes, and wetland in the Western Lake Michigan Drainages are affected by water-quality problems. In addition to contaminant exposure, much aquatic habitat—especially wetland—is modified or lost each year to urban and suburban development, agriculture, and logging activities. Populations of several species of biota appear to be in decline in certain areas. Although water quality in the Fox River/Green Bay area has improved in the past several decades, studies of aquatic biota have found declines in populations of some species, health problems among various organisms, and high contaminant concentrations in plant and animal tissues. Results of these studies indicate a need for continued remediation in the Fox River/Green Bay area. In contrast, water quality of rivers and lakes in the northern forested region of the study area (Subbasins 1 and 2, and northern areas of Subbasin 3) generally shows less effect of human activity, and aquatic communities in these water bodies are more representative of unaltered conditions than are those of more southern streams, which may be significantly altered by human activity. These current conditions are different from those that existed prior to logging in the northern forested region and do not represent pristine conditions.

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TABLES 1–4

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area

[Subbasins: 1, Ford/Escanaba; 2, Menominee/Oconto/Peshtigo; 3, Fox/Wolf; 4, Sheboygan/Manitowoc/Twin; 5, Milwaukee]

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Albert (1995)	All	x				x	x	x	x	x	x
Amin (1981)	5		x			x		x			
Amin and others (1973)	5		x			x		x			
Amin and others (1993)	4		x			x		x			
Anderson and Hamerstrom (1967)	2–5	x							x		
Anderson (1978)	3		x		x						
Ankley and others (1990)	3		x			x					
Ankley, Lodge and others (1992)	3		x			x					
Arndt (1996)	3	x					x				
Auer (1982)	All	x						x			
Avery and others (1995)	3		x					x			
Baker (1928a)	2–5	x				x					
Baker (1928b)	2–5	x				x					
Balcer and others (1986)	3		x					x			
Ball (1982)	2–5	x								x	
Ball and Marshall (1978)	2–3	x		x							
Barnes and Wagner (1981)	1–2	x								x	
Becker (1964)	3		x					x			
Becker (1983)	2–5	x						x			
Becker and Johnson (1970)	2–5	x						x			
Benyus (1989)	All	x			x		x		x		x
Benyus and others (1992)	All	x				x		x	x		x
Berry (1943)	1–2	x				x					
Beule (1979)	3	x			x	x		x	x	x	
Blake and others (1991)	1–2	x							x		
Blake and others (1994)	1–2	x							x		
Blasczyk and Barbeau (1994)	3		x			x					
Blasczyk and others (1992)	3		x			x					

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Blum (1993)	2	x		x							
Bosley (1978)	2	x								x	
Bowers and Kline (1991)	5		x							x	
Brazner and Magnuson (1994)	1–3	x						x			
Brosseau (1983)	3		x			x					
Bruch (1993)	3		x					x			
Brynildson (1980)	2–5	x					x	x			x
Bumby (1977)	3		x		x						
Burch (1991)	1–2	x				x					
Burghardt and others (1995)	5	x					x				
Burton and others (1991)	1		x	x		x		x			
Call and others (1991)	3		x			x					
Casper (1985)	2–5	x					x				x
Casper (1987a)	5	x					x				
Casper (1987b)	5		x				x				
Casper (1987c)	2–5	x					x				
Casper (1989)	5	x					x				
Casper (1992a)	5	x					x				
Casper (1992b)	5	x					x				
Casper (1993)	2–5	x					x				
Casper (1995)	2–5	x					x				
Casper (1996)	2–5	x					x				
Chabot (1996)	2–5	x					x		x		
Coberly and Horrall (1980)	2–5	x						x			
Cochran (1989)	2		x				x				x
Cochran (1992)	3–4		x				x				
Cochran (1994a)	4		x				x				
Cochran (1994b)	3		x					x			

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Cochran and Hesse (1994)	3		x					x			
Cochran and others (1990)	4		x			x					
Cochran and others (1993)	4	x						x			
Cook (1991)	1–2	x				x					
Crandon Mining Company (1995)	2		x	x	x	x		x			x
Craven and others (1986)	3–4	x							x		
Cummings and Mayer (1992)	All	x				x					
Curtis (1971)	2–5	x								x	
Czajkowski (1993)	3		x					x			
Czajkowski and others (1996)	3		x					x			
Darlington (1964)	1–2	x			x						
Detwiler and others (1991)	1–2	x				x					x
Dlutkowski and others (1987)	2–5	x					x				
Drought (1987a)	5		x				x				
Drought (1987b)	5		x				x				
Drought (1987c)	5		x				x				
DuVall (1983)	3	x						x			
Edgren (1949a)	3		x				x				
Edgren (1949b)	5		x				x				
Eggers and Reed (1987)	2–5	x								x	
Ehlinger (1994)	5	x						x			
Eichhorst (1985)	3		x						x		x
Engemann and Flanagan (1991)	1–2	x				x					
Epstein and others (1996)	3		x				x				x
Erickson and Mahan (1982)	2		x					x			
Evers (1992)	1–2	x									x
Fago (1984)	5		x					x			
Fago (1985)	4		x					x			

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Fago (1992)	2–5	x						x			
Fassett (1957)	All	x			x					x	
Fassett (1976)	2–5	x			x					x	
FERC (1995)	2		x		x	x	x	x	x	x	x
Fewless (1986)	3		x		x						
Finley (1976)	2–5	x								x	
Flowers (1975)	2–5	x				x					x
Frelich (1979)	4		x		x					x	
Fruth and others (1988)	2–5	x							x		x
Garrison and Knauer (1983)	3		x	x		x		x			
Gates (1970)	3		x						x	x	
Gerber (1994a)	All	x			x						
Gerber (1994b)	All	x			x						
Gerber and Les (1994)	All	x			x						
Gilbertson and Watermolen (1996)	2–5	x					x				
Goedde and Coble (1981)	3		x					x			
Goodrich (1932)	1–2	x				x					
Granlund and others (1994)	1–2	x							x		
Grittinger (1971)	5		x							x	
Gromme (1963)	2–5	x							x		x
Hanrahan (1974)	3		x							x	
Harding and Holman (1990)	1–2	x					x				
Harding and Holman (1992)	1–2	x					x				
Harris (1988)	All	x							x		
Harris and others (1977)	2	x							x	x	
Harris and others (1983)	2	x							x	x	
Harris and others (1988)	All	x		x	x	x		x	x	x	
Harris and others (1993)	3		x						x		

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Harris and Trick (1979)	2–5	x							x		x
Hart (1990)	4		x							x	x
Hatleli and others (1995)	3		x					x			
Havlik (1993)	2–5	x				x					x
Heard and Burch (1966)	1–2	x				x					
Heath (1992)	2		x				x				
Herman (1988)	2		x			x					
Hewett and Simonson (1995)	3	x						x			
Hilliker and others (1994)	5		x							x	x
Hilsenhoff (1975)	2–5	x				x					
Hilsenhoff (1977)	2–4	x				x					
Hilsenhoff (1981)	2–5	x				x					
Hilsenhoff (1982)	All	x				x					
Hilsenhoff (1987)	2–5	x				x					
Hilsenhoff (1988a)	2–5	x				x					
Hilsenhoff (1988b)	2–5	x				x					
Hilsenhoff (1993a)	2–5	x				x					
Hilsenhoff (1993b)	2–5	x				x					
Hilsenhoff (1994)	2–5	x				x					
Hilsenhoff (1995)	2–5	x							x		
Hilsenhoff and Billmyer (1973)	2–4	x				x					
Hilsenhoff and Schmude (1992)	2–5	x				x					
Hilsenhoff and others (1972)	2		x			x					
Hine and others (1981)	2–5	x					x				
Hobbs and Jass (1988)	2–5	x				x					
Hoffman (1987)	2–5	x							x		x
Hoffman (1994)	3		x					x			
Hoffman and others (1996)	3		x					x			

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Holman and others (1993)	1–2	x					x				
Holtan (1990a)	2–5	x						x			
Holtan (1990b)	2–5	x						x			
Holtan (1990c)	2–5	x						x			
Holtan (1991)	2–5	x						x			
Hooper (1993)	3		x			x					
Howmiller and Beeton (1971)	2–4	x				x					
Hubbs and Lagler (1941)	All	x						x			
Hunt and Jahn (1966)	3	x							x		
Hunt (1966)	3		x					x			
Hunt (1968)	3		x					x			
Hunt (1971)	3		x					x			
Hunt (1974)	3		x					x			
Hunt (1982)	3		x					x			
Hunt (1988)	2–5	x						x			
Hurley and Garrison (1993)	3	x		x							
Institute of Paper Chemistry (1973)	3		x	x							
Jackson (1927)	4	x							x		
Jass (1995)	2–5	x				x					
Jass and Klausmeier (1990a)	All	x				x					
Jass and Klausmeier (1990b)	2–5	x				x					
Jass and Klausmeier (1995a)	3–5	x				x					
Jass and Klausmeier (1995b)	2–5	x				x					
Jesien and Coble (1979)	3		x					x			
Johnson (1996)	1–2	x					x				
Johnson and Becker (1970)	2–5	x						x			
Juday (1943)	3	x		x		x				x	
Jung and others (1996)	3		x				x				

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Kahl (1993)	3		x		x	x			x		
Kassulke (1994)	5		x			x		x			
Keough (1986)	4		x							x	
Kleinert (1970)	2–5	x							x	x	
Klemm (1991)	All	x				x					
Kline (1990a)	5		x							x	
Kline (1990b)	5		x							x	
Kline (1991)	5		x							x	x
Knudsen (1962)	2–3	x				x	x	x	x	x	
Kocik and others (1991)	1	x						x			
Koutnik and Padilla (1994)	2–5	x				x					
Kraft (1995)	2–5	x				x					
Kraft and others (1995)	3		x					x			
Kroeger (1986)	5		x							x	
Kubiak and others (1989)	3	x							x		
Lagler and Lagler (1943)	1–2	x				x					
Langhurst and Schoenike (1990)	3		x					x			
Legler and others (1995)	2–5	x				x					
Leithoff (1994)	5		x				x		x	x	
Leitner and others (1991)	4–5	x								x	x
Lenz and Rheaume (1995)	2–5	x				x					
Leonard and Leonard (1962)	1–2	x				x					
Lillie (1995)	2–3	x				x					x
Lillie and others (1993)	2–5	x		x							
Loftus and Waldon (1992)	All	x						x			
Ludwig (1984)	All	x							x		
Lund (1994)	1–2	x								x	
Lyons (1989)	2–5	x						x			

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Lyons (1990)	All	x						x			
Lyons (1991)	2–5	x						x			
Lyons (1992a)	1,3	x						x			
Lyons (1992b)	2–5	x						x			
Lyons (1996)	3	x						x			
Lyons and Kanehl (1993)	2–5	x						x			
Lyons and Kempinger (1992)	3	x						x			
Lyons and others (1996)	2–5	x						x			
Mandrak (1989)	All	x						x			
Marinac (1976)	2		x					x			
Markert (1981)	3		x			x					
Marsh (1891a)	3		x			x					
Marsh (1891b)	3		x			x					
Marsh (1903)	3		x	x		x					
Mason and Wegner (1970)	2	x						x			
Masterson and Bannerman (1994)	5		x			x					
Mathiak (1979)	2–5	x				x					
Matteson (1983)	2–5	x							x		x
Matteson (1985)	2–5	x							x		x
Matteson (1986)	2–5	x							x		x
Matteson (1988)	2–5	x							x		x
McAllister (1991)	2	x			x						
McRae and Edwards (1994)	2		x					x			
Mecozzi (1988)	2–3	x						x			
Mecozzi (1989a)	2–5	x						x			
Mecozzi (1989b)	2–3	x						x			
Mecozzi (1989c)	2–5	x						x			
Mecozzi (1989d)	2–5	x						x			

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Mecozzi (1995)	2–5	x		x	x	x		x	x		
Meyers and others (1992)	2		x					x			
Michigan DNR (1992)	1–2	x				x		x		x	
Michigan DNR (1994b)	1–2	x		x	x	x		x		x	
Michigan DNR (1995)	1–2	x					x		x		x
Modlin (1970)	5	x			x					x	
Moody (1989)	3		x					x			
Moore and Lychwick (1980)	2,4		x					x			
Mossman (1988)	2–5	x							x		x
Mossman and Hine (1985)	2–5	x					x				x
Mossman and others (1984)	3		x						x		x
Mossman and others (1991)	3		x				x				
Nichols (1988)	2–3	x			x						
Nichols (1990)	2–5	x			x						
Nichols (1992)	2–4	x			x					x	
Nichols and Martin (1990)	2–5	x		x							
Nichols and Vennie (1991)	2–5	x		x							
Novitzki (1979)	2–5	x								x	
Omernik and Gallant (1988)	All	x								x	
Ortmann and Walker (1922)	1–2	x				x					
Otis (1988)	3		x					x			
Otis and Staggs (1988)	3		x					x			
Otis and Weber (1982)	3		x					x			
Paruch (1979)	2	x						x			
Peterson (1991)	2–5	x						x			
Porter (1991)	1–2	x				x					
Postupalsky (1989)	1–2	x							x		
Prescott (1962)	All	x		x							

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Priegel (1967)	3	x						x			
Priegel (1969)	3		x					x			
Priegel (1970)	3	x						x			
Priegel (1971)	3		x					x			
Priegel (1973)	1–2	x						x			
Priegel and Wirth (1975)	3		x					x			
Priegel and Wirth (1978)	3		x					x			
Quinlan (1989)	3		x	x		x		x			
Read (1976)	2–5	x								x	x
Redmond and others (1993)	5		x							x	
Reed (1988)	2–5	x								x	
Reed and Lang (1992)	3		x				x				
Reinartz (1990)	5		x							x	
Reinartz (1994)	5		x							x	
Reinartz and Warne (1990)	5		x							x	
Reinartz and Warne (1993)	5		x							x	
Reinartz and others (1994)	5		x							x	
Rheaume and others (1996)	3–5	x			x	x		x		x	
Rhew (1992)	3		x	x							
Rickett (1924)	3		x	x	x						
Robbins (1971)	2–5	x							x		
Robbins (1977)	2–5	x							x		
Robbins (1982)	2–5	x							x		
Robinson (1996)	3		x		x						
Rost and others (1989)	2		x	x	x	x		x			
Sabol (1983)	3		x		x						
Sager and others (1996)	3		x		x						
Scharf and Shugart (1981)	2–5	x							x		

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Scheirer (1988)	3		x					x			
Schimpff (1993)	5		x					x			
Schmidt (1995)	3	3						x			
Schmude and Hilsenhoff (1986)	2–5	x				x					
Simonich (1992)	2–5	x								x	x
Simonson and Lyons (1995)	3	x						x			
Simonson and others (1994)	2–5	x						x			
Smith (1920)	2–5	x		x							
Smith (1924)	2–5	x		x							
Smith (1978)	2	x			x						
Smith, Tom (1993)	2–5	x							x		
Smith, W.A. (1993)	2–5	x				x					x
Snider (1991)	1–2	x				x					
Sontag (1995)	5		x	x			x				
Stern (1990)	2–5	x				x					x
Strassburg (1991)	2–5	x						x			
Summers (1991)	All	x				x					
Swindale and Curtis (1957)	3–5	x			x						
Szczytko (1989)	2–5	x				x					
Szczytko (1995)	3		x			x					
Taft (1989a)	1		x			x					
Taft (1989b)	2		x			x					
Taft (1991a)	1		x			x		x		x	
Taft (1991b)	1		x			x		x		x	
Taft (1991c)	1		x			x		x		x	
Taft (1991e)	1		x			x		x			
Taft (1994)	1		x			x		x			
Techlow and Mossman (1985)	3	x							x		

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Temple and Cary (1987)	2–5	x							x		x
The Nature Conservancy (1988)	3–5		x		x		x	x	x	x	x
Thompson (1995)	5		x							x	
Threinen (1958)	2–5	x				x					
Threinen and Poff (1963)	2–5	x						x			
Thuemler (1985)	2		x					x			
Torke (1976)	2–5	x				x					
Trick (1982)	2–3	x							x		
U.S. Environmental Protection Agency (1991)	3		x					x			
U.S. Geological Survey (1995)	All	x		x		x		x		x	
University of Wisconsin Sea Grant Institute (1996)	2–5	x				x					
Vogt (1981)	2–5	x					x				x
Vondracek (1977)	2, 4		x					x			
Voss (1972)	1–2	x			x					x	
Voss (1985)	1–2	x			x					x	
Walter and Burch (1957)	1–2	x				x					
Walters (1992)	2–5	x			x					x	
Wang and others (1995)	3–5	x				x		x			
Watermolen (1989)	4	x					x				
Watermolen (1992a)	4		x				x				
Watermolen (1992b)	3		x				x				
Watermolen (1992c)	2–5	x					x				
Watermolen (1995)	2–5	x					x				
Watermolen (1996a)	2–5	x					x				x
Watermolen (1996b)	2–5	x				x					
Watermolen and Casper (1993)	4		x				x				
Watermolen and Chandler (1993)	2–5	x				x					

Table 1. Studies of populations and community structure of aquatic biota in the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated							
		Regional	Local	Algae	Macrophytes	Invertebrates	Amphibians & reptiles	Fish	Birds	Wetland & flood plain vegetation	Endangered & threatened species
Watermolen and Gilbertson (1996)	2–5	x					x				
Watermolen and Haen (1994)	2–5	x				x					
Weber (1976)	3		x					x			
Weber and Les (1982)	3		x					x			
Weber and Otis (1984)	3	x						x			
Weise and others (1995)	2–5	x							x		
Welsch (1988)	2–5	x			x						
Wenger and others (1990)	4	x						x			
Wheeler and Hunt (1994)	3		x						x		
Wheeler and March (1979)	3		x						x	x	
Wheeler and others (1984)	3		x			x	x	x	x		
Williams and others (1993)	All	x				x					x
Wilson (1991)	1–2	x				x		x			x
Wisconsin DOA (1995)	2–5	x								x	
Wisconsin DNR (1990)	2–5	x			x			x		x	
Wisconsin DNR (1991b)	5		x	x		x		x			x
Wisconsin DNR (1993b)	3	x		x	x	x		x	x	x	
Wisconsin DNR (1994)	2–5	x				x		x		x	
Wisconsin/Michigan DNR (1990)	2	x		x	x	x		x	x	x	
Yencha (1993)	4	x			x		x		x	x	
Yoder (1994)	3		x			x					
TOTAL NUMBER OF STUDIES	**356**	**224**	**134**	**27**	**40**	**109**	**54**	**124**	**56**	**64**	**42**

Table 2. Studies of the health of aquatic biota from the Western Lake Michigan Drainages study area
[Subbasins: 1, Ford/Escanaba; 2, Menominee/Oconto/Peshtigo; 3, Fox/Wolf; 4, Sheboygan/Manitowoc/Twin; 5, Milwaukee]

Literature citation	Subbasins	Study scale		Biota investigated				Effect investigated					
		Regional	Local	Invertebrates	Amphibians & reptiles	Fish	Birds	Disease	Lesions	Malformations	Reproductive Impairment	Tumors	Other
Amin and others (1973)	5		x			x							x
Ankley, Lodge, and others (1992)	3		x	x		x	x		x	x	x	x	
Baumann and others (1991)	2–3	x				x			x			x	
Crandon Mining Company (1995)	2		x			x		x		x			x
Custer and others (1995)	3		x				x				x		
DeVore and Eaton (1983)	2		x			x				x			
Dykstra and others (1995)	3		x				x				x		
Fox, Collins, and others (1991)	3	x					x			x	x		
Fox, Weseloh, and others (1991)	3	x					x			x			
Giesy and others (1995)	2	x					x				x		
Harris (1988)	All	x					x			x	x		
Harris and others (1993)	3		x				x				x		
Hine and others (1981)	3–4	x			x			x			x		
Hoffman and others (1987)	3		x				x				x		
Hoffman and others (1993)	3		x				x			x	x		
Jung and others (1996)	3		x		x					x	x		
Klemm (1991)	1	x		x							x		x
Kubiak and others (1989)	3	x					x	x		x	x		
Larson and others (1996)	4	x					x			x	x		
Matteson (1985)	All	x					x				x		
Meyer and others (1996)	2–5	x					x				x		x
Mossman and others (1984)	3		x				x				x		
Rattner and others (1993)	3		x				x			x			x
Rost (1983)	2		x			x							x
Scheirer and Coble (1991)	3		x			x							x
Techlow and Mossman (1985)	3–4		x				x				x		
Tillitt and others (1992)	3	x					x				x		
Trick (1982)	2–3	x					x				x		x
Wisconsin DNR (1993b)	3	x				x	x			x	x	x	
Wisconsin/Michigan DNR (1990)	2	x				x	x			x		x	x
TOTAL NUMBER OF STUDIES	**30**	**15**	**15**	**2**	**2**	**9**	**21**	**3**	**2**	**13**	**21**	**4**	**9**

Table 3. Studies of chemical concentrations in tissues of aquatic biota from the Western Lake Michigan Drainages study area

[Subbasins: 1, Ford/Escanaba; 2, Menominee/Oconto/Peshtigo; 3, Fox/Wolf; 4, Sheboygan/Manitowoc/Twin; 5, Milwaukee]

Literature citation	Subbasins	Study scale		Biota investigated				Contaminant investigated				
		Regional	Local	Invertebrates	Amphibians & Reptiles	Fish	Birds	Inorganics	Organics	PCB's	Dioxins	Others
Ankley, Cook, and others (1992)	3		x	x		x			x	x		
Ankley and others (1993)	3		x				x		x	x		
Call and others (1991)	3		x	x		x			x	x		x
Campbell and Talbot (1993)	2		x			x		x	x	x		
Clark and others (1984)	All	x				x		x	x	x		
Crandon Mining Company (1995)	2		x	x		x		x				x
Custer and others (1995)	3		x				x		x	x		
Custer and Custer (1995)	3		x				x		x	x		
DeVault (1985)	3–5	x				x			x	x		
DeVita and Crunkilton (1994)	5		x	x		x			x	x		
DuVall (1983)	3	x				x						x
Dykstra and others (1995)	3		x				x		x	x		
Giesy and others (1994)	2	x				x		x	x	x	x	
Giesy and others (1995)	2	x				x	x	x	x	x	x	
Grieb and others (1990)	1	x				x		x				
Harris and others (1993)	3		x				x		x	x		
Hesselberg and others (1991)	All	x				x			x	x		
Hoffman and others (1987)	3		x				x		x	x	x	
Hoffman and others (1993)	3		x				x	x	x	x		
Jones and others (1993)	3		x				x		x	x	x	
Jung and others (1996)	3		x		x				x	x		
Kleinert and Degurse (1972)	1–3	x				x	x	x				
Kleinert and others (1968)	2–5		x			x			x			x
Kleinert and others (1974)	1–3	x				x		x				
Klemm (1991)	1	x		x				x	x			
Kubiak and others (1989)	3	x					x		x	x	x	
Larson and others (1996)	4	x					x		x	x	x	
Lathrop and others (1989)	2–4	x				x		x				
Lathrop and others (1991)	2–5	x				x		x				
Lowe and others (1985)	4	x				x		x				

Table 3. Studies of chemical concentrations in tissues of aquatic biota from the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated				Contaminant investigated				
		Regional	Local	Invertebrates	Amphibians & Reptiles	Fish	Birds	Inorganics	Organics	PCB's	Dioxins	Others
Mac and others (1985)	3		x	x		x		x	x	x		
Masterson and Bannerman (1994)	5		x	x		x		x	x	x		
May and McKinney (1981)	4	x				x		x				
Meyer and others (1996)	2–5	x					x	x				
Michigan DEQ (1995)	1	x				x		x	x	x	x	
Michigan DNR (1991b)	2		x			x		x	x	x	x	
Michigan DNR (1992)	1–2	x				x		x	x	x		
Michigan DNR (1994a)	1–2	x				x		x	x	x		
Michigan DNR (1994b)	1–2	x				x		x	x	x		
Pariso and others (1984)	All	x				x		x	x	x		
Peterman and Delfino (1990)	3		x			x		x	x	x		
Phillipson and Puma (1980)	4		x			x			x		x	
Rattner and others (1993)	3		x				x		x	x		
Rost and others (1989)	2		x	x		x		x	x	x		
Schmitt (1990)	4	x				x		x	x	x		
Schmitt and Brumbaugh (1990)	4	x				x		x				
Schmitt and others (1981)	4	x				x			x	x		
Schmitt and others (1983)	4	x				x			x	x		
Schmitt and others (1985)	4	x				x			x	x		
Schmitt and others (1990)	4	x				x			x	x		
Scudder and others (1995)	All	x		x				x				
Sullivan and Delfino (1982)	3		x			x		x	x	x		
Sullivan and others (1983)	3		x			x			x	x		
Taft (1989c)	1		x			x		x	x	x		
Taft (1991d)	2		x			x		x	x	x	x	
Tillitt and others (1991)	2	x					x		x	x	x	x
Tillitt and others (1992)	3	x					x		x	x		
Tillit and others (1993)	3	x					x				x	
Turgeon and Robertson (1995)	3,5	x		x				x	x	x		
U.S. EPA (1992a and b)	All	x				x		x	x	x	x	
U.S. Geological Survey (1995)	All	x		x		x		x	x	x		

Table 3. Studies of chemical concentrations in tissues of aquatic biota from the Western Lake Michigan Drainages study area—Continued

Literature citation	Subbasins	Study scale		Biota investigated				Contaminant investigated				
		Regional	Local	Invertebrates	Amphibians & Reptiles	Fish	Birds	Inorganics	Organics	PCB's	Dioxins	Others
Veith and others (1981)	3	x				x			x	x		
Wisconsin DNR (1991a)	2	x				x		x	x	x		
Wisconsin DNR (1991b)	5		x			x	x	x	x	x		
Wisconsin DNR (1993a)	2–5	x				x		x	x	x		
Wisconsin DNR (1993b)	3	x				x	x	x	x	x		
Wisconsin DNR (1994)	2–5	x		x		x		x	x	x	x	
Wisconsin DNR (1995)	2–5	x				x		x	x	x		
Wisconsin/Michigan DNR (1990)	2	x		x	x	x	x	x	x	x	x	
TOTAL NUMBER OF STUDIES	**69**	**42**	**27**	**13**	**2**	**50**	**20**	**41**	**56**	**53**	**15**	**5**

Table 4. Studies of toxicity to aquatic biota from the Western Lake Michigan Drainages study area

[Subbasins: 1, Ford/Escanaba; 2, Menominee/Oconto/Peshtigo; 3, Fox/Wolf; 4, Sheboygan/Manitowoc/Twin; 5, Milwaukee; Test Type L = Lab, F = Field, L/F = Both Lab and Field]

Literature citation	Subbasins	Study scale		Biota investigated					Test type	Toxicity assessed					
		Regional	Local	Algae	Invertebrates	Amphibians & reptiles	Fish	Birds		Carcinogenicity	Growth	Mutagenicity	Reproduction	Survival	Other
Ankley and others (1990)	3		x	x	x		x		L		x			x	x
Ankley, Lodge, and others (1992)	3		x	x	x		x	x	L/F	x	x	x	x	x	
Auer and Auer (1987)	3		x				x		L/F					x	
Auer and Auer (1990)	3		x				x		F				x	x	
Avery and others (1995)	3		x				x		L/F		x			x	
Balcer and others (1986)	3		x				x		F		x		x	x	
Call and others (1991)	3		x		x		x		L/F			x		x	
Campbell and Talbot (1993)	3		x				x		L/F					x	x
Custer and others (1995)	3		x					x	L/F				x		
Davenport and Spacie (1991)	All	x			x				L					x	
Delfino (1985)	3		x				x		F					x	
Fabacher and others (1991)	2–3	x					x		L	x				x	
Giesy and others (1995)	2	x						x	F				x	x	x
Harris and others (1993)	3	x						x	F				x	x	
Hine and others (1981)	2–5	x				x			F		x			x	
Hoffman and others (1987)	3		x					x	L		x	x	x	x	
Hoffman and others (1993)	3		x					x	L/F		x		x	x	x
Hokanson and Lien (1985)	3		x				x		L/F		x			x	
Ingersoll and others (1991)	5		x		x				L		x		x	x	
Jung and others (1996)	3		x			x			L/F		x		x	x	
Klemm (1991)	1	x			x				L/F				x	x	
Kubiak and others (1989)	3	x						x	F		x		x	x	
Lien and others (1986)	3		x		x		x		L		x		x	x	
Mac and others (1985)	3		x		x		x		L/F					x	
Michigan DNR (1992)	1–2	x		x	x		x		L				x	x	
Michigan DNR (1994b)	1–2	x			x		x		L/F		x		x	x	x
Ramcheck (1995)	5		x		x		x		L/F				x	x	
Rost and others (1989)	2		x		x		x		L		x			x	
Tillitt and others (1991)	2	x						x	L						x
Tillitt and others (1992)	3	x						x	L				x	x	
Tillitt and others (1993)	2–3		x					x	L						x
Wisconsin DNR (1993b)	3	x			x		x		L					x	
Wisconsin DNR (1994)	2–5	x			x		x		L/F		x		x	x	
Wisconsin/Michigan DNR (1990)	2	x			x		x		L/F					x	
TOTAL NUMBER OF STUDIES	**34**	**14**	**20**	**3**	**15**	**2**	**20**	**10**	**12L; 7F; 15L/F**	**2**	**15**	**3**	**18**	**31**	**7**

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APPENDIX A

APPENDIX A. AQUATIC BIOTA OF THE WESTERN LAKE MICHIGAN DRAINAGES STUDY AREA

Tables in this section list the aquatic biota found in the study area by scientific name, common name, and other characteristics available from literature sources. Included are the following:

TABLES

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan
[Compiled from Bumby, 1977; Curtis, 1971; Engel, 1985; Fassett, 1957; Fassett, 1976; Gerber, 1994b; Hotchkiss, 1972; Kahl, 1993; Kline, 1991; Modlin, 1970; Nichols and Martin, 1990; Smith, 1978; Welsch, 1988; Nomenclature according to Gleason and Cronquist, 1991]

Scientific name	Common name	Growth habit
Class : Equisetopsida		
Order: Equisetales		
Family: Equisetaceae (horsetails)		
Equisetum fluviatile	Horsetail	Emergent
Class : Isoetopsida		
Order: Isoetales		
Family: Isoetaceae (quillworts)		
Isoetes echinospora	Spiny-spore quillwort	Submersed
Isoetes macrospora	Lake quillwort	Submersed
Class : Liliopsida (Monocots)		
Order: Alismatales		
Family: Alismataceae (water-plaintains)		
Alisma gramineum	Water plaintain	Emergent
Alisma triviale	Water plaintain	Emergent
Sagittaria cuneata	Arrowhead/duck potato	Emergent
Sagittaria graminea	Arrowhead/duck potato	Emergent
Sagittaria latifolia	Arrowhead/duck potato	Emergent
Sagittaria rigida	Stiff arrowhead	Emergent
Order: Arales		
Family: Acoraceae (sweet flags)		
Acorus calamus	Sweet flag	Emergent
Family: Araceae (arums)		
Calla palustris	Calla lily	Emergent
Order: Cyperales		
Family: Cyperaceae (sedges)		
Carex spp.	Sedge	Emergent
Cyperus spp.	Sedge	Emergent
Dulichium arundinaceum	Three-way sedge	Emergent
Eleocharis acicularis	Needle rush/slender spikerush	Emergent
Eleocharis equisetoides	Northern jointed spikerush	Emergent
Eleocharis palustris	Creeping spikerush	Emergent
Eleocharis quadrangulata	Squarestem spikerush	Emergent
Eleocharis robbinsii	Triangle spikerush	Emergent
Eleocharis tenuis	Spikerush	Emergent
Scirpus acutus	Hard roundstem bulrush	Emergent
Scirpus americanus	Three-square bulrush	Emergent
Scirpus atrovirens	Bulrush	Emergent
Scirpus cyperinus	Wool grass	Emergent
Scirpus fluviatilis	River bulrush	Emergent
Scirpus heterochaetus	Slender bulrush	Emergent
Scirpus validus	Soft roundstem bulrush	Emergent

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Family: Poaceae (grasses)		
Calamagrostis canadensis	Bluejoint grass	Emergent
Leersia oryzoides	Rice cut-grass	Emergent
Glyceria striata	Manna grass	Emergent
Phalaris arundinacea	Reed canary grass	Emergent
Phragmites australis	Common reed	Emergent
Zizania aquatica	Wild rice	Emergent
Order: Eriocaulales		
Family: Eriocaulaceae (pipeworts)		
Eriocaulon aquaticum	Pipewort	Submersed
Order: Hydrocharitales		
Family: Hydrocharitaceae (frogbits)		
Elodea canadensis	Waterweed	Submersed
Elodea nuttalli	Waterweed	Submersed
Vallisneria americana	Wild celery/tape grass	Submersed
Order: Juncales		
Family: Juncaceae (rushes)		
Juncus spp.	Rush	Emergent
Order: Liliales		
Family: Iridaceae (irises)		
Iris lacustris	Dwarf lake iris	Emergent
Iris pseudacorus	Water flag	Emergent
Iris versicolor	Blue flag	Emergent
Iris virginica	Iris	Emergent
Family: Pontederiaceae (water hyacinths)		
Pontederia cordata	Pickerelweed	Emergent
Zosterella dubia	Water stargrass	Submersed
Order: Najadales		
Family: Lemnaceae (duckweeds)		
Lemna minor	Lesser duckweed	Floating
Lemna perpusilla	Least duckweed	Floating
Lemna trisulca	Star duckweed	Floating
Spirodela polyrhiza	Big duckweed	Floating
Wolffia columbiana	Common watermeal	Floating
Wolffia punctata	Dotted watermeal	Floating
Family: Najadaceae (water-nymphs)		
Najas flexilis	Slender naiad/bushy pondweed	Submersed
Najas gracillima	Bushy pondweed	Submersed
Najas guadalupensis	Southern naiad	Submersed
Najas marina	Spiny naiad	Submersed

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Family: Potamogetonaceae (pondweeds)		
Potamogeton alpinus	Red pondweed	Submersed
Potamogeton amplifolius	Large-leaf pondweed	Submersed
Potamogeton confervoides	Alga pondweed	Submersed
Potamogeton crispus	Curly-leaf pondweed	Submersed
Potamogeton diversifolius	Water-thread pondweed	Submersed
Potamogeton epihydrus	Leafy pondweed	Submersed
Potamogeton filiformis	Thread-lead pondweed	Submersed
Potamogeton foliosus	Leafy pondweed	Submersed
Potamogeton friesii	Frie's pondweed	Submersed
Potamogeton gramineus	Variable pondweed	Submersed
Potamogeton illinoensis	Pondweed	Submersed
Potamogeton natans	Floating-leaf pondweed	Submersed
Potamogeton nodosus	American pondweed	Submersed
Potamogeton oakensianus	Pondweed	Submersed
Potamogeton obtusifolius	Pondweed	Submersed
Potamogeton pectinatus	Sago pondweed	Submersed
Potamogeton praelongus	Whitestem pondweed	Submersed
Potamogeton pusillus	Slender pondweed	Submersed
Potamogeton richardsonii	Richardson pondweed	Submersed
Potamogeton robbinsii	Robbin's pondweed	Submersed
Potamogeton spirillus	Spiral-fruited pondweed	Submersed
Potamogeton strictifolus	Pondweed	Submersed
Potamogeton vaginatus	Swift-water pondweed	Submersed
Potamogeton vaseyi	Vasey's pondweed	Submersed
Potamogeton zosteriformis	Flat-stemmed pondweed	Submersed
Family: Ruppiaceae (ditch-grasses)		
Ruppia maritima	Wigeon grass/ditch grass	Submersed
Family: Zannichelliaceae (horned pondweeds)		
Zannichellia palustris	Horned pondweed	Submersed
Order: Typhales		
Family: Sparganiaceae (bur reeds)		
Sparganium americanum	Bur reed	Emergent
Sparganium angustifolium	Narrow-leaf bur reed	Emergent
Sparganium chlorocarpum	Bur reed	Emergent
Sparganium eurycarpum	Bur reed	Emergent
Sparganium fluctuans	Floating-leaf bur reed	Emergent
Family: Typhaceae (cattails)		
Typha angustifolia	Common cattail/broadleaf cattail	Emergent
Typha latifolia	Narrow-leaf cattail	Emergent

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Class : Magnoliopsida (Dicots)		
Order: Araliales		
Family: Apiaceae (carrots)		
Sium suave	Water-parsnip	Emergent
Cicuta bulberifera	Bulbiliferous water-hemlock	Emergent
Cicuta maculata	Common water-hemlock	Emergent
Order: Asterales		
Family: Asteraceae (asters)		
Bidens beckii	Water marigold	Emergent
Bidens cernua	Beggar ticks	Emergent
Bidens connata	Beggar ticks	Emergent
Eupatorium maculatum	Joe-pye weed	Emergent
Eupatorium perfoliatum	Boneset	Emergent
Eupatorium rugosum	Snakeroot	Emergent
Order: Callitrichales		
Family: Callitrichaceae (water-starworts)		
Callitriche hermaphroditica	Water starwort	Submersed
Callitriche stagnalis	Water starwort	Submersed
Callitriche pallustris	Water starwort	Submersed
Family: Hippuridaceae (mare's tails)		
Hippuris vulgaris	Mare's tail	Submersed
Order: Campanulales		
Family: Campanulaceae (bellflowers)		
Campanula aparinoides	Bellflower	Emergent
Family: Lobeliaceae (lobelias)		
Lobelia dortmanna	water-lobelia	Submersed
Order: Capparales		
Family: Brassicaceae (mustards)		
Armoracia lacustris	Lake-cress	Emergent
Cardamine pensylvanica	Pennsylvania bitter-cress	Emergent
Cardamine pratensis	Cuckoo-flower	Emergent
Cardamine rhomboidea	Spring-cress	Emergent
Rorippa nasturtium-aquaticum	Water-cress	Submersed
Order: Cornales		
Family: Cornaceae (dogwoods)		
Cornus sericea	Red-osier dogwood	Emergent
Order: Ericales		
Family: Ericaceae (heaths)		
Chamaedaphne calyculata	Leather leaf	Emergent
Order: Gentianales		
Family: Asclepiadaceae (milkweeds)		
Asclepias incarnata	Swamp milkweed	Emergent

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Order: Haloragales		
Family: Haloragaceae (water-milfoils)		
Myriophyllum alterniflorum	Little water-milfoil	Submersed
Myriophyllum aquaticum	Parrot's-feather	Submersed
Myriophyllum farwellii	Farwell's water-milfoil	Submersed
Myriophyllum heterophyllum	Various-leaved water-milfoil	Submersed
Myriophyllum humile	Water-milfoil	Submersed
Myriophyllum sibiricum	Common water-milfoil	Submersed
Myriophyllum spicatum	Eurasian water-milfoil	Submersed
Myriophyllum tenellum	Dwarf water-milfoil	Submersed
Myriophyllum verticillatum	Green milfoil	Submersed
Order: Lamiales		
Family: Lamiaceae (mints)		
Lycopus uniflorus	Northern water-horehound	Emergent
Scutellaria galericulata	Marsh skullcap	Emergent
Order: Myrtales		
Family: Lythraceae (loosestrifes)		
Decodon verticillatus	Swamp loosestrife	Emergent
Lythrum alatum	Winged loosestrife	Emergent
Lythrum salicaria	Purple loosestrife	Emergent
Didiplis diandra	Water-purslane	Submersed
Family: Onograceae (evening primroses)		
Ludwigia palustris	Common water-primrose	Emergent
Order: Plantaginales		
Family: Plantaginaceae (plaintains)		
Littorella uniflora	Plaintain shoreweed	Submersed
Order: Polygonales		
Family: Polygonaceae (smartweeds)		
Polygonum amphibium	Water smartweed	Submersed
Polygonum careyi	Carey's smartweed	Emergent
Polygonum punctatum	Dotted smartweed	Submersed
Order: Primulales		
Family: Primulaceae (primroses)		
Lysimachia terrestris	Bulbil-loosestrife	Emergent
Lysimachia thrysiflora	Swamp-loosestrife	Emergent
Order: Nymphaeales		
Family: Cabombaceae (water-shields)		
Brasenia schreberi	Water-shield	Submersed

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Family: Ceratophyllaceae (hornwarts)		
Ceratophyllum demersum	Coontail/Hornwart	Submersed
Ceratophyllum echinatum	Spiny hornwart	Submersed
Family: Nelumbonaceae (lotus-lilies)		
Nelumbo lutea	American lotus-lily	Emergent
Family: Nymphaeaceae (water-lilies)		
Nuphar advena	Yellow water lily	Emergent
Nuphar microphylla	Yellow water lily	Emergent
Nuphar variegata	Yellow water lily	Emergent
Nymphaea odorata	Fragrant water lily	Emergent
Order: Ranunculales		
Family: Ranunculaceae (buttercups)		
Caltha palustris	Marsh marigold	Emergent
Ranunculus flabellaris	Yellow water-crowfoot	Emergent
Ranunculus longirostris	White water-crowfoot	Submersed
Ranunculus flammula	Creeping spearwort	Submersed
Ranunculus sceleratus	Cursed crowfoot	Submersed
Ranunculus trichophyllus	White water-crowfoot	Submersed
Order: Rosales		
Family: Saxifragaceae (saxifrages)		
Penthorum sedoides	Ditch stonecrop	Emergent
Family: Rosaceae (roses)		
Potentilla palustris	Marsh cinquefoil/Marsh-potentilla	Emergent
Order: Salicales		
Family: Salicaceae (willows)		
Salix spp.	Willow	Emergent
Order: Scrophulariales		
Family: Lentibulariaceae (bladderworts)		
Utricularia geminiscapa	Hidden-flower bladderwort	Submersed
Utricularia gibba	Humped/creeping bladderwort	Submersed
Utricularia intermedia	Flat-leaf/northern bladderwort	Submersed
Utricularia minor	Lesser bladderwort	Submersed
Utricularia purpurea	Purple/spotted bladderwort	Submersed
Utricularia resupinata	Lavender/resupinate bladderwort	Submersed
Utricularia vulgaris	Common bladderwort	Submersed
Family: Scrophylariaceae (figworts)		
Chelone glabra	White turtlehead	Emergent
Gratiola aurea	Yellow hedge-hyssop/Goldenpert	Emergent
Veronica anagallis-aquatica	Water-speedwell	Emergent

Table A1. Aquatic macrophytes of Wisconsin and the Upper Peninsula of Michigan—Continued

Scientific name	Common name	Growth habit
Order: Solanales		
Family: Solanaceae (nightshades)		
Solanum dulcamara	Nightshade/bittersweet	Emergent
Order: Theales		
Family: Elatinaceae (waterworts)		
Elatine minima	Waterwort	Emergent
Class : Bryopsida/Musci (mosses)		
Order: Bryales		
Fontinalis spp.	Water moss	Submersed
Class : Hepaticopsida		
Order: Marchantiales (thallose liverworts)		
Riccia fluitans	Slender riccia	Submersed
Class : Charophyceae		
Order: Charales		
Family: Characeae (Stoneworts)		
Chara sp. or spp.	Muskgrass	Submersed
Nitella sp. or spp.	Stonewort	Submersed

Table A2. Aquatic invertebrates of the Western Lake Michigan Drainages study area
[Compiled from Burch, 1991; Detweiler and others, 1991; Edmondson, 1959; Engemann and Flanagan, 1991; Hilsenhoff, 1981; Klemm, 1991; Porter, 1991; Snider, 1991; Nomenclature according to Pennak, 1989 (protozoa to mollusks); Merritt and Cummins, 1996 (insects)]

Scientific name	Common name	Level of identification commonly used
Phylum: Sarcomastigigophora	Protozoa	Genus
Phylum: Ciliophora	Protozoa	Genus
Phylum: Porifera	Sponges	
Class: Demospongea		
Order: Haplosclerina		
Family: Spongillidae	Freshwater sponges	Species
Phylum: Coelenterata	Hydroids and jellyfish	
Class: Hydrozoa	Hydras	
Order: Hydroida		
Family: Hydridae		Genus
Phylum: Platyhelminthes	Flatworms	
Class: Turbellaria		Class
Phylum: Nemertea	Proboscis worms	Order/Genus
Phylum: Gastrotricha	Gastrotrichs	Order
Phylum: Rotifera	Rotifers	Order/Genus
Phylum: Nematoda	Roundworms	Order/Genus
Phylum: Nematomorpha	Horsehair worms/gordian worms	
Order: Gordioidea		
Family: Gordiidae		Genus
Family: Chordodidae		Genus
Phylum: Tardigrada	Water bears	Genus/species
Phylum: Bryozoa	Moss animalcules	
Class: Phylactolaemata		Species
Phylum: Entoprocta		Species
Phylum: Annelida		
Class: Oligochaeta	Aquatic earthworms	
Order: Haplotaxida		
Family: Haplotaxidae		Species
Family: Naididae		Species
Family Tubificidae		Species
Order: Lumbriculida		
Family: Lumbriculidae		Species
Class: Hirudinea	Leeches	
Order: Gnathobdellida		
Family: Hirudinidae		Species
Order: Pharyngobdellida		
Family: Erpobdellidae		Species

Table A2. Aquatic invertebrates of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	Level of identification commonly used
Order: Rhynchobellida		
Family: Glossiphoniidae		Species
Family: Piscicolidae		Species
Phylum: Arthropoda		
Class: Crustacea		
Order: Anostraca	Fairy shrimps	Genus
Order: Cladocera	Water fleas	Species
Order: Conchostraca	Clam shrimps	Genus
Order: Branchiura	Copepods	Species
Order: Eucopepoda	Copepods	Species
Order: Ostracoda	Seed shrimps	Species
Order: Isopoda	Aquatic sow bugs	
Family: Asellidae		Genus
Order: Amphipoda	Scuds/sideswimmers	
Family: Crangonyctidae		Genus/Species
Family: Gammaridae		Genus/Species
Family: Talitridae		Genus/Species
Order: Decapoda		
Family: Cambaridae	Crayfishes	Genus/Species
Family: Palaemonidae	Prawns	Genus/Species
Class: Arachnoidea		
Order: Acari	Water mites	Genus
Class: Entognatha		
Order: Collembola	Springtails	Family
Class: Insecta/Hexapoda		
Order: Ephemeroptera	Mayflies	
Family: Ametropodidae		Genus
Family: Baetidae		Genus/Species
Family: Baetiscidae		Species
Family: Caenidae		Genus
Family: Ephemeridae		Genus
Family: Ephemerellidae		Species
Family: Heptageniidae		Genus/Species
Family: Leptophlebiidae		Genus
Family: Metretopodidae		Genus
Family: Oligoneuriidae		Genus
Family: Polymitarcyidae		Species
Family: Potamanthidae		Genus
Family: Siphlonuridae		Genus
Family: Tricorythidae		Genus

Table A2. Aquatic invertebrates of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	Level of identification commonly used
Order: Odonata	Dragonflies and damselflies	
Family: Aeshnidae		Species
Family: Calopterygidae		Genus
Family: Coenagrionidae		Family/Genus
Family: Cordulegastridae		Species
Family: Corduliidae		Species
Family: Gomphidae		Species
Family: Lestidae		Species
Family: Libellulidae		Species
Order: Plecoptera	Stoneflies	
Family: Capniidae		Genus
Family: Chloroperlidae		Genus
Family: Leuctridae		Genus
Family: Nemouridae		Genus/Species
Family: Perlidae		Species
Family: Perlodidae		Species
Family: Peltoperlidae		Genus
Family: Pteronarcyidae		Genus/Species
Family: Taeniopterygidae		Genus
Order: Hemiptera	True bugs	
Family: Belostomatidae	Giant water bugs	Genus
Family: Corixidae	water boatmen	Genus
Family: Gerridae	Water striders	Genus
Family: Hebridae	Velvet water bugs	Genus
Family: Hydrometridae	Water measurers	Genus
Family: Mesoveliidae	Water treaders	Genus
Family: Naucoridae	Creeping water bugs	Genus
Family: Nepidae	Water scorpions	Genus
Family: Notonectidae	Back swimmers	Genus
Family: Pleidae	Pygmy back swimmers	Genus
Family: Veliidae	Broad-shouldered water striders	Genus
Order: Megaloptera		
Family: Corydalidae	Fishflies/Dobsonflies	Species
Family: Sialidae	Alderflies	Genus
Order: Neuroptera	Spongilla flies	Genus
Family: Sisyridae		
Order: Tricoptera	Caddisflies	
Family: Brachycentridae		Genus
Family: Glossosomatidae		Genus
Family: Helicopsychidae		Species
Family: Hydropsychidae		Species

Table A2. Aquatic invertebrates of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	Level of identification commonly used
Order: Tricoptera—Continued	Caddisflies	
Family: Hydroptilidae		Genus/Species
Family: Lepidostomatidae		Genus
Family: Leptoceridae		Genus/Species
Family: Limnephilidae		Genus
Family: Molannidae		Genus
Family: Odontoceridae		Genus
Family: Philopotamidae		Genus/Species
Family: Phryganeidae		Genus
Family: Polycentropodidae		Genus
Family: Psychomyiidae		Species
Family: Rhyacophilidae		Genus/Species
Family: Sericostomatidae		Genus
Order: Lepidoptera	Aquatic moths	
Family: Pyralidae		Genus
Order: Coleoptera	Aquatic beetles	
Family: Chrysomelidae	Leaf beetles	Family
Family: Curculionidae	Weevils	Family
Family: Dryopida	Long-toes water beetles	Genus
Family: Dytiscidae	Predaceous diving beetles	Genus
Family: Elmidae	Riffle beetles	Genus/Species
Family: Gyrinidae	Whirligig beetles	Genus
Family: Haliplidae	Crawling water beetles	Genus
Family: Hydraenidae	Minute moss beetles	Genus
Family: Hydrophilidae	Water scavenger beetle	Genus
Family: Noteridae	Burrowing water beetles	Genus
Family: Psephenidae	Water Pennies	Species
Family: Scirtidae	Marsh beetles	Family
Order: Diptera		
Family: Athericidae	Snipe flies	Species
Family: Blephariceridae	Net-winged midges	Genus/Species
Family: Ceratopogonidae	No-see-ums/biting midges	Family/Genus/Species
Family: Chaoboridae	Phantom midges	Genus
Family: Chironomidae	Midges	Genus/Species
Family: Culicidae	Mosquitoes	Genus
Family: Dixidae	Dixid midges	Genus
Family: Dolichopodidae	Lone-legged flies	Family
Family: Empididae	Dance fly	Family/Genus
Family: Ephydridae	Shore and Brine flies	Family/Genus
Family: Muscidae	House flies	Species
Family: Psychodidae	Moth flies	Genus

Table A2. Aquatic invertebrates of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	Level of identification commonly used
Order: Diptera—Continued		
Family: Ptychopteridae	Phantom crane flies	Genus
Family: Sciomyzidae	Marsh flies	Family/Genus
Family: Simuliidae	Black flies	Genus/Species
Family: Stratiomyidae	Soldier flies	Genus
Family: Syrphidae	Flower fly/rattail maggots	Family/Genus
Family: Tabanidae	Horse and Deer flies	Genus/Species
Family: Tanyderidae	Primitive crane flies	Genus/Species
Family: Tipulidae	Crane flies	Genus/Species
Phylum: Mollusca		
Class: Gastropoda	Snails and limpets	
Order: Mesogastropoda		
Family: Bithyniidae		Genus/Species
Family: Hydrobiidae		Genus/Species
Family: Pomatiopsidae		Genus/Species
Family: Pleuroceridae	River snails	Genus/Species
Family: Valvatidae	Round-mouth snails	Family/Genus/Species
Family: Viviparidae	Beaded snails	Family/Genus/Species
Order: Limnophila		
Family: Ancylidae	Limpets	Family/Genus/Species
Family: Lymnaeidae	Pond snails	Family/Genus/Species
Family: Physidae	Left-handed snails	Family/Genus/Species
Family: Planorbidae	Wheel/orb snails	Family/Genus/Species
Class: Pelecypoda	Clams and mussels	
Order: Veneroida		
Family: Dreisseniidae		Family/Genus/Species
Family: Sphaeriidae	Fingernail clams	Family/Genus/Species
Order: Unionoida		
Family: Unionidae	Mussels	Family/Genus/Species

Table A3. Amphibians and aquatic-associated reptiles of the Western Lake Michigan Drainages study area
[Compiled from Hine and others, 1981; Vogt, 1981; Conant and Collins, 1991; Benyus and others, 1992; Casper, 1996]

Scientific name	Common name	General Area of Aquatic Occurrence
Order: Anura (Frogs and Toads)		
Family: Bufonidae (TrueToads)		
Bufo americanus	Eastern American toad	Sedge meadow, marsh, swamp, pond
Family: Hylidae (Treefrogs)		
Acris crepitans blanchardi	Blanchard's cricket frog	Sedge meadow, marsh, swamp, pond
Hyla versicolor	Gray treefrog	Sedge meadow, marsh, swamp, pond, stream
Pseudacris crucifer	Spring peeper	Sedge meadow, marsh, swamp, pond, lake
Pseudacris triseriata	Chorus frog	Sedge meadow, marsh, pond
Family: Ranidae (True Frogs)		
Rana catesbeiana	Bullfrog	Marsh, pond, lake, stream
Rana clamitans	Green frog	Marsh, pond, lake, stream
Rana palustris	Pickerel frog	Sedge meadow, marsh, swamp, pond, lake, stream
Rana pipiens	Leopard frog	Sedge meadow, marsh, swamp, pond, lake, stream
Rana septentrionalis	Mink frog	Marsh, swamp, pond, lake, stream
Rana sylvatica	Wood frog	Marsh, pond
Order: Caudata (Salamanders)		
Family: Ambystomatidae (Mole Salamanders)		
Ambystoma jeffersonianum	Jefferson salamander	Marsh, pond, lake
Ambystoma laterale	Blue-spotted salamander	Marsh, pond
Ambystoma maculatum	Spotted salamander	Pond
Ambystoma tigrinum	Tiger salamander	Sedge meadow, swamp, marsh, pond
Ambystoma tremblayi	Tremblay's salamander	Pond
Family: Plethodontidae (Lungless salamanders)		
Hemidactylium scutatum	Four-toed salamander	Bog, pond
Family: Proteidae (Waterdogs and mudpuppies)		
Necturus maculosus	Mudpuppy	Pond, lake, stream
Family: Salamandridae (Newts)		
Notophthalmus viridescens	Central/Eastern newt	Marsh, pond, lake, stream
Order: Squamata (Snakes)		
Family: Colubridae		
Elaphe vulpina	Fox snake	Sedge meadow, swamp
Nerodia sipedon	Northern water snake	Marsh, swamp, bog, pond, lake, stream
Regina septemvittata	Queen snake	Pond, stream
Storeria dekayi	Brown snake	Marsh, swamp, bog
Storeria occipitomaculata	Redbelly snake	Swamp, bog
Thamnophis sauritus	Northern ribbon snake	Bog
Thamnophis sirtalis	Common garter snake	Sedge meadow, marsh, along streams
Order: Testudines (Turtles)		
Family: Chelydridae (Snapping Turtles)		
Chelydra serpentina	Snapping turtle	Marsh, pond, lake, stream

Table A3. Amphibians and aquatic-associated reptiles of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General Area of Aquatic Occurrence
Family: Kinosternidae (Musk and Mud Turtles)		
Stenotherus odoratus	Musk turtle/Stinkpot	Pond, lake, stream
Family: Emydidae (Water and Box Turtles)		
Chrysemys picta	Painted turtle	Marsh, pond, lake, stream
Clemmys insculpta	Wood turtle	Sedge meadow, marsh, pond, stream
Emydoidea blandingii	Blanding's turtle	Marsh, pond, lake, stream
Graptemys geographica	Map turtle	Lake, stream
Family: Trionychidae (Softshell Turtles)		
Apalone spinifera	Spiny softshell	Pond, lake, stream

Table A4. Fishes of streams of the Western Lake Michigan Drainages study area

[Nomenclature according to American Fisheries Society, 1991; Explanation of abbreviations: a, abundant, species taken frequently and in large numbers; c, common, species taken frequently and in moderate numbers; u, uncommon, species taken infrequently and in very small numbers; r, rare, species taken at highly infrequent intervals with one or two specimens per collection (Becker, 1983); E, species endangered; T, species is threatened; W, species on watched list in Wisconsin (Fago, 1992). A (P) signifies that the species is on the protected fishes list for Michigan (Michigan Department of Natural Resources, East Lansing, Mich., written commun., 1993).]

Scientific name	Common name	General area of occurrence	Relative abundance
Class: Cephalaspidomorphi (Lampreys)			
Order: Petromyzontiformes			
Family: Petromyzontiformes (Lampreys)			
Ichthyomyzon unicuspis	Silver lamprey	Upper Fox and Wolf River basins, Menominee River	u
Ichthyomyzon fossor	Northern brook lamprey	Menominee, Peshtigo, and lower Wolf River	c
Ichthyomyzon castaneus	Chestnut lamprey	Upper Fox River basin	u
Lampetra appendix	American brook lamprey	Tomorrow, East Twin, and Wausaukee Rivers, Three Mile Creek, and Cedar River	u
Petromyzon marinus	Sea lamprey	(Lake Michigan and Green Bay tributaries)	c
Class: Osteichthyes (Bony Fishes)			
Order: Amiiformes			
Family: Amiidae (bowfins)			
Amia calva	Bowfin	Fox and Wolf River Basins	c
Order: Anguilliformes			
Family: Anguillidae (freshwater eels)			
Anguilla rostrata	American eel	Lake Michigan and Green Bay tributaries	W
Order: Ascipenseriformes			
Family: Acipenseridae (sturgeons)			
Acipenser fulvescens	Lake sturgeon	Menominee River, and Wolf and Fox River Basins	W, T (MI)
Order: Atheriniformes			
Family: Atherinidae (silversides)			
Labidesthes sicculus	Brook silverside	(Sparsely scattered in the southwestern part of the study unit)	c
Family: Cyprinodontidae (killifishes)			
Fundulus diaphanus	Banded killifish	(Scattered across the study unit except in the extreme northwestern part)	u
Fundulus notatus	Blackstripe topminnow	Upper Fox and Milwaukee Rivers	u
Order: Clupeiformes			
Family: Clupeidae (herrings)			
Alosa pseudoharengus	Alewife	Lake Michigan and Green Bay tributary mouths	c
Dorosoma cepedianum	Gizzard shad	Fox River system	a
Order: Cypriniformes			
Family: Catastomidae (suckers)			
Carpoides cyprinus	Quillback	Fox and Wolf Rivers	c
Catostomus commersoni	White sucker	(Most widespread fish in Wisconsin, present in the entire study area)	a

Table A4. Fishes of streams of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General area of occurrence	Relative abundance
Family: Catastomidae (suckers)—Continued			
Erimyzon sucetta	Lake chubsucker	Fox and Wolf Rivers	W
Hypentelium nigricans	Northern hog sucker	Upper Fox, Wolf, Menominee, and Cedar River systems	c
Ictiobus cyprinellus	Bigmouth buffalo	Fox and Wolf River Basins	unknown
Minytrema melanops	Spotted sucker	Wolf River system	c
Moxostoma anisurum	Silver redhorse	Fox, Wolf, Manitowoc, Ahnapee, and Menominee Rivers	c–u
Moxostoma carinatum	River redhorse	Wolf River system	T (MI,WI)
Moxostoma erythrurum	Golden redhorse	Wolf and Milwaukee Rivers	c
Moxostoma macrolepidotum	Shorthead redhorse	(Larger rivers across the study unit)	c
Moxostoma valenciennesi	Greater redhorse	(A few medium to large rivers)	T (WI)
Family: Cyprinidae (minnows and carps)			
Campostoma anomalum	Central stoneroller	Tomorrow River (and a few streams in the southern part of the study unit)	a
Campostoma oligolepis	Largescale stoneroller	(Medium-sized, swift-flowing streams in the central part of the study unit)	a
Carassius auratus	Goldfish	(Extreme southeastern part of the study unit)	c
Clinostomus elongatus	Redside dace	(Disjunct populations in small headwater streams)	W (P)
Couesius plumbeus	Lake chub	(Mouths of Lake Michigan and Green Bay tributaries)	c
Cyprinella spiloptera	Spotfin shiner	Fox and Wolf River systems, Milwaukee River, tributaries to southern Green Bay	a
Cyprinus carpio	Common carp	(Many waters in the study unit, especially the southern half)	a–c
Hybognathus hankinsoni	Brassy minnow	(Small, slow-moving streams, especially in the western and northern parts of the study unit)	c
Luxilus cornutus	Common shiner	(Found throughout the study unit)	a
Luxilus chrysocephalus	Striped shiner	(Southeastern part of the study unit)	E (WI)
Lythrurus umbratilis	Redfin shiner	(Southeastern part of the study unit)	T (WI)
Margariscus margarita	Pearl dace	(Small streams, especially in the northern part of the study unit)	c
Nocomis biguttatus	Hornyhead chub	(Clear-water, medium-sized streams throughout the southern 3/4 of the study unit)	c
Notemigonus crysoleucas	Golden shiner	(Weedy waters in the entire study unit)	a–c
Notropis anogenus	Pugnose shiner	(A couple of disjunct populations)	T (WI)
Notropis atherinoides	Emerald shiner	Wolf and Fox River Basins (and streams in the southeast part of the study unit)	a–c
Notropis chalybaeus	Ironcolor shiner	(Found twice in Wolf and Fox River Basins, probably extirpated in the study unit)	unknown
Notropis dorsalis	Bigmouth shiner	Fox, Wolf, Pike, and Root Rivers	c

Table A4. Fishes of streams of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General area of occurrence	Relative abundance
Family: Cyprinidae (minnows and carps)—Continued			
Notropis heterodon	Blackchin shiner	(Streams near lakes, most of in the study unit)	c–u
Notropis heterolepis	Blacknose shiner	(Clear, vegetated waters over most of the study unit)	c
Notropis hudsonius	Spottail shiner	Fox and Wolf River systems, Milwaukee River	c
Notropis rubellus	Rosyface shiner	(Medium-sized, clear, swift streams except extreme northwestern part of the study unit)	a–u
Notropis stramineus	Sand shiner	(Scattered over most of the study unit)	c–u
Notropis texanus	Weed shiner	Wolf, upper Fox, Peshtigo Rivers	W
Notropis volucellus	Mimic shiner	(Scattered over most of the study unit)	c–u
Opsopoeodus emiliae	Pugnose minnow	Fox and Wolf River systems	W
Phoxinus eos	Northern redbelly dace	(Entire study unit, especially the northern half)	a
Phoxinus erythrogaster	Southern redbelly dace	(Southern half of the study unit)	u–r
Phoxinus neogaeus	Finescale dace	Upper Wolf, upper Fox, and Menominee River Basins, and Escanaba, Cedar, and Rapid Rivers	c–u
Pimephales notatus	Bluntnose minnow	(Entire study unit, most successful fish species in Wisconsin)	a
Pimephales promelas	Fathead minnow	(Widely distributed over the study unit)	a–c
Pimephales vigilax	Bullhead minnow	Upper Fox River	unknown
Rhinichthys atratulus	Blacknose dace	(Small, cool, headwater streams; less common in clear, medium-sized streams)	a–c
Rhinichthys cataractae	Longnose dace	(Fast water in medium-sized streams in the northern part of the study unit)	a
Semotilus atromaculatus	Creek chub	(Entire study unit–small to medium-sized streams)	a
Order: Gadiformes			
Family: Gadidae (cods)			
Lota lota	Burbot	(Scattered throughout most of the study unit, especially the Fox and Wolf River systems	c
Order: Gasterosteiformes			
Family: Gasterostidae (sticklebacks)			
Culaea inconstans	Brook stickleback	(Many headwater streams in the study unit)	c
Pungitius pungitius	Ninespine stickleback	(Occassionally in Lake Michigan tributary mouths)	u
Order: Lepisosteiformes			
Family: Lepisosteidae (gars)			
Lepisosteus osseus	Longnose gar	Wolf and Fox River basins	c
Lepisosteus platostomus	Shortnose gar	Lower Wolf and lower Fox Rivers	c
Order: Osteoglossiformes			
Family: Hiodontidae (mooneyes)			
Hiodon tergisus	Mooneye	Lower Fox, Wolf, Embarrass Rivers	c–u

Table A4. Fishes of streams of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General area of occurrence	Relative abundance
Order: Perciformes			
Family: Centrarchidae (sunfishes)			
Ambloplites rupestris	Rock bass	(Entire study unit)	c
Lepomis cyanellus	Green sunfish	(Scattered over the entire study unit, especially the southern part)	c–u
Lepomis gibbosus	Pumpkinseed	(Entire study unit)	c
Lepomis gulosus	Warmouth	(Widely scattered areas of the Fox and Wolf River headwaters)	u–r
Lepomis macrochirus	Bluegill	(Entire study unit)	a–c
Lepomis megalotis	Longear sunfish	Milwaukee River system, southern Green Bay tributaries	T (WI)
Micropterus dolomieu	Smallmouth bass	(Medium to large streams in the entire study unit)	c
Micropterus salmoides	Largemouth bass	(Medium to large rivers in the entire study unit)	a
Pomoxis annularis	White crappie	Fox, Wolf, and Root Rivers	c–u
Pomoxis nigromaculatus	Black crappie	(Entire study unit)	c
Family: Percichthyidae (temperate basses)			
Morone chrysops	White bass	Fox and Wolf River systems	a–c
Morone mississippiensis	Yellow bass	(Primarily a lake fish, occassionally found in streams in the southern half of the study unit)	u
Family: Percidae (perches)			
Ammocrypta clara	Western sand darter	Wolf River	W
Etheostoma caeruleum	Rainbow darter	Upper Fox, Tomorrow-Waupaca, and Little Wolf Rivers	c
Etheostoma exile	Iowa darter	(Most of the study unit, in medium-sized streams)	c–u
Etheostoma flabellare	Fantail darter	(Small, warm streams in the southern and eastern parts of the study unit)	a
Etheostoma microperca	Least darter	Wolf and upper Fox River systems (and rivers in the southeast)	W
Etheostoma nigrum	Johnny darter	(Entire study unit)	a–c
Etheostoma zonale	Banded darter	(Central-western part of the study unit)	c–u
Perca flavescens	Yellow perch	(Entire study unit)	a–c
Percina caprodes	Logperch	(Most of the study unit in medium and large rivers)	c
Percina maculata	Blackside darter	(Most of the study unit except the northwest)	c
Percina phoxocephala	Slenderhead darter	Embarrass and Little Wolf Rivers	u
Percina shumardi	River darter	Lower Wolf and Fox River systems	r
Stizostedion canadense	Sauger	Lower Wolf, Fox, and Menominee River systems	a–u
Stizostedion vitreum	Walleye	(Most of the study unit)	c–u
Family: Sciaenidae (drums)			
Aplodinotus grunniens	Freshwater drum	(Lower Wolf and Fox River systems)	c–u

Table A4. Fishes of streams of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General area of occurrence	Relative abundance
Order: Percopsiformes			
Family: Aphredoderidae (pirate perches)			
Aphredoderus sayanus	Pirate perch	Embarrass River	W
Family: Percopsidae (trout-perches)			
Percopsis omiscomaycus	Trout-perch	(Lake Michigan and Green Bay tributary mouths)	c
Order: Salmoniformes			
Family: Esocidae (pikes)			
Esox lucius	Northern pike	(Sluggish areas of many rivers in the study unit)	c
Esox masquinongy	Muskellunge	(Scattered throughout medium to large rivers in the study unit)	u
Family: Salmonidae (trouts)			
Coregonus clupeaformis	Lake whitefish	Brule and Menominee Rivers and tributaries	unknown
Oncorhynchus gorbuscha	Pink salmon	Peshtigo and Ford Rivers	r
Oncorhynchus kisutch	Coho salmon	(Lake Michigan and Green Bay tributaries)	a–c
Oncorhynchus mykiss	Rainbow trout	(Fast, whitewater sections of coldwater streams)	c
Oncorhynchus tshawytscha	Chinook salmon	(Lake Michigan tributaries)	a–c
Salmo trutta	Brown trout	(Many coldwater streams in the study unit)	c
Salvelinus fontinalis	Brook trout	(Cold, clear headwater streams, especially in northern parts of the study unit)	c (north) u(south)
Family: Umbridae (mudminnows)			
Umbra limi	Central mudminnow	(Many marshes, ditches, and streams)	a–c
Order: Scorpaeniformes			
Family: Cottidae (sculpins)			
Cottus bairdi	Mottled sculpin	(Headwater streams, especially in the northern part)	c
Order: Siluriformes			
Family: Ictaluridae (bullhead catfishes)			
Ameiurus melas	Black bullhead	(Most of the study unit)	a
Ameiurus natalis	Yellow bullhead	(Many clear, medium-sized streams of the southern 3/4 of the study unit)	c–u
Ameiurus nebulosus	Brown bullhead	(Widely scattered distribution in sluggish streams except in the southeastern part of the study unit)	u
Ictalurus punctatus	Channel catfish	(Larger streams in the southern half of the study unit)	c–u
Noturus flavus	Stonecat	Wolf and Milwaukee River systems	c–u
Noturus gyrinus	Tadpole madtom	(Many medium to large streams in the study unit)	c
Pylodictis olivaris	Flathead catfish	Fox and Wolf Rivers	c–u

Table A5. Aquatic birds of the Western Lake Michigan Drainages study area
[Compiled from Hilsenhoff, 1995; Mossman and others, 1984; National Geographic Society, 1983; Robbins, 1982; Temple and Cary, 1987]

Scientific name	Common name	General Area of Aquatic Occurrence
Order: Anseriformes		
Family: Anatidae (Swans, Geese, Ducks)		
Aix sponsa	Wood duck	Open woodlands near ponds and rivers
Anas acuta	Northern pintail	Marshes, ponds, lakes
Anas americana	American wigeon	Marshes, ponds, shallow lakes
Anas clypeata	Northern shoveler	Marshes, ponds, bays
Anas crecca	Green-winged teal	Marshes, ponds, lakes
Anas discors	Blue-winged teal	Marshes, ponds, lakes
Anas platyrhynchos	Mallard	Marshes, ponds, shallow lakes
Anas rubripes	American black duck	Marshes, woodland lakes and streams marshes
Anas strepera	Gadwall	Marshes, ponds, lakes
Aythya affinis	Lesser scaup	Marshes, ponds, lakes, sheltered bays
Aythya americana	Redhead	Marshes, ponds, lakes
Aythya collaris	Ring-necked duck	Marshes, woodland ponds, small lakes
Aythya marila	Greater scaup	Large open lakes, bays
Aythya valisineria	Canvasback	Open lakes, marshes
Branta canadensis	Canada goose	Wetlands, open or forested areas near water
Bucephala albeola	Bufflehead	Woodlands near ponds and small lakes, bays
Bucephala clangula	Common goldeneye	Lakes, rivers, sheltered coastal areas
Bucephala islandica	Barrow's goldeneye	Ponds, lakes, woodlands near water, rivers
Chen caerulescens	Snow goose	Marshes, ponds, lakes
Clangula hyemalis	Oldsquaw	Coasts
Cygnus columbianus	Tundra swan	Marshes, ponds, lakes
Cygnus olor	Mute swan	Marshes, ponds, lakes
Histrionicus histrionicus	Harlequin duck	Along swift streams, coasts
Lophodytes cucullatus	Hooded merganser	Woodland ponds, rivers, sheltered waters
Melanitta fusca	White-winged scoter	Inland lakes, rivers, coasts
Melanitta nigra	Black scoter	Woodland lakes, rivers, ponds
Melanitta perspicillata	Surf scoter	Woodlands near water, coasts
Mergus merganser	Common merganser	Woodland lakes and rivers
Mergus serrator	Red-breasted merganser	Woodland lakes and rivers, coasts
Oxyura jamaicensis	Ruddy duck	Marshes, lakes, ponds, shallow bays
Order: Ciconiiformes		
Family: Ardeidae (Herons and Egrets)		
Ardea herodias	Great blue heron	Ponds, lakes, marshes
Botaurus lentiginosus	American bittern	Ponds, lakes, streams, marshes
Bubulcus ibis	Cattle egret	Ponds, lakes, streams, marshe
Butorides striatus	Green-backed heron	Ponds, lakes, streams, marshes
Casmerodius albus	Great egret	Ponds, lakes, streams, marshes
Ixobrychus exilis	Least bittern	Ponds, lakes, streams, marshes
Nycticorax nycticorax	Black-crowned night heron	Ponds, lakes, streams, marshes
Nycticorax violaceus	Yellow-crowned night heron	Ponds, lakes, streams, marshes

Table A5. Aquatic birds of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General Area of Aquatic Occurrence
Order: Charadriiformes		
Family: Charadriidae (Plovers)		
Charadrius vociferus	Killdeer	Riverbanks, open marshes
Family: Laridae (Skuas, Jaegers, Gulls, and Terns)		
Chlidonias niger	Black tern	Marshes
Larus argentatus	Herring gull	Islands, marshes
Larus delawarensis	Ring-billed gull	Islands, marshes
Larus hyperboreus	Glaucous gull	Great Lakes lakeshores
Larus marinus	Greater black-backed gull	Great Lakes lakeshores
Larus philadelphia	Bonaparte's gull	Great Lakes lakeshores
Larus thayeri	Thayer's gull	Great Lakes lakeshores
Sterna forsteri	Forster's tern	Islands, marshes
Sterna hirundo	Common tern	Islands, marshes
Sterna caspia	Caspian tern	Marshes, rivers, lakes
Family: Scolopacidae (Sandpipers)		
Actitus macularia	Spotted sandpiper	Sheltered streams, ponds, lakes, or marshes
Arenaria interpres	Ruddy turnstone	Great Lakes lakeshores and bays
Calidris alba	Sanderling	Great Lakes lakeshores and bays
Calidris alpina	Dunlin	Great Lakes lakeshores and bays
Calidris bairdii	Baird's sandpiper	Marshes, mudflats, lakeshores
Calidris fuscicollis	White-rumped sandpiper	Marshes, mudflats, lakeshores
Calidris melanotos	Pectoral sandpiper	Marshes, ponds
Calidris minutilla	Least sandpiper	Marshes, shores of rivers and bays
Calidris pusilla	Semipalmated sandpiper	Marshes, wetlands, ponds, lakes
Catoptrophorus semipalmatus	Willet	Mud flats, marshes, lakeshores
Charadrius vociferus	Killdeer	Lakeshores, riverbanks
Gallinago gallinago	Common snipe	Marshes, bogs, riverbanks
Limnodromus griseus	Short-billed dowitcher	Great Lakes lakeshores and bays
Limnodromus scolopaceus	Long-billed dowitcher	Great Lakes lakeshores and bays
Limosa haemastica	Hudsonian godwit	Mud flats, marshes, lakeshores
Phalaropus tricolor	Wilson's phalarope	Marshes, ponds, shallow lakes, reservoirs
Scolopax minor	American woodcock	Swamps, moist woodlands
Tringa solitaria	Solitary sandpiper	Shallow backwaters, ponds, bays
Tringa flavipes	Lesser yellowlegs	Mud flats, marshes, inland lakeshores
Tringa melanoleuca	Greater yellowlegs	Mud flats, marshes, inland lakeshores
Order: Coraciiformes		
Family: Alcedinidae (Kingfishers)		
Ceryle alcyon	Belted kingfisher	Woodland ponds, rivers, lakes, bays
Order: Falconiformes		
Family: Accipitridae (Kites, Hawks, Eagles)		
Accipiter cooperi	Cooper's hawk	Woodlands near streams
Buteo lineatus	Red-shouldered hawk	Moist woodlands near streams

Table A5. Aquatic birds of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General Area of Aquatic Occurrence
Family: Accipitridae (Kites, Hawks, Eagles)—Continued		
Circus cyaneus	Northern harrier	Wetlands, marshes
Falco peregrinus	Peregrine falcon	River, lakes
Haliaeetus leucocephalus	Bald eagle	Rivers, lakes
Pandion haliaetus	Osprey	Rivers, lakes
Order: Gaviiformes		
Family: Gaviidae (Loons)		
Gavia immer	Common Loon	Lakes
Gavia stellata	Red-throated Loon	Lakes
Order: Gruiformes		
Family: Gruidae (Cranes)		
Grus canadensis	Sandhill crane	Marshes, streams, ponds
Family: Rallidae (Rails, Gallinules, Coots)		
Fulica americana	American coot	Marshes, wetlands, ponds, lakes
Gallinula chloropus	Common moorhen	Marshes, ponds, calm rivers
Porzana carolina	Sora	Marshes, wetlands
Rallus elegans	King rail	Marshes, wetlands
Rallus limicola	Virginia rail	Marshes, wetlands
Order: Passeriformes		
Family: Certhiidae (Creepers)		
Certhia americana	Brown creeper	Swampy forests, mixed forests near water
Family: Emberizidae (Warblers and Sparrows)		
Agelaius phoeniceus	Red-winged blackbird	Marshes, sloughs
Dendroica cerulea	Cerulean warbler	Lowlands, swamps, mixed forests near water
Euphagus carolinus	Rusty blackbird	Wet woodlands, bogs, swamps
Melospiza georgiana	Swamp sparrow	Marshes, swamps, streams
Pheucticus ludovicianus	Rose-breasted grosbeak	Streamside thickets
Pipilo erythrophthalmus	Rufous-sided towhee	Streamside thickets
Seiurus noveboracensis	Northern waterthrush	Lowland hardwood forest
Xanthocephalus xanthocephalus	Yellow-headed blackbird	Marshes, lakeshores
Family: Muscicapidae (Thrushes)		
Catharus fuscescens	Veery thrush	Moist woodlands, streamside thickets
Catharus ustulatus	Swainson's thrush	Moist woodlands, swamps
Hylocichla mustelina	Wood thrush	Moist woodlands, swamps
Family: Troglodytidae (Wrens)		
Cistothorus palustris	Marsh wren	Reedy marshes, cattail swamps
Cistothorus platensis	Sedge wren	Marshes
Family: Tyrannidae (Tyrant flycatchers)		
Empidonax alnorum	Alder flycatcher	Bogs, ponds, alder thickets
Empidonax traillii	Willow flycatcher	Alongside streams
Empidonax virescens	Acadian flycatcher	Lowland hardwood forests, swamps

Table A5. Aquatic birds of the Western Lake Michigan Drainages study area—Continued

Scientific name	Common name	General Area of Aquatic Occurrence
Order: Pelicaniformes		
Family: Phalacrocoracidae (Cormorants)		
Phalacrocorax auritus	Double-crested cormorant	Great Lakes lakeshores and bays
Order: Podicipediformes		
Family: Podicipedidae (Grebes)		
Podiceps auritus	Horned grebe	Sheltered lakes, ponds
Podiceps grisegena	Red-necked grebe	Shallow lakes
Podilymbus podiceps	Pied-billed grebe	Marshy ponds, sloughs
Order: Strigiformes		
Family: Strigidae (Typical Owls)		
Strix varia	Barred owl	Woodlands near riverbottoms, swamps

Table A6. Federal-listed endangered and threatened aquatic biota of the Western Lake Michigan Drainages study area
[Data from U.S. Fish and Wildlife Service, Green Bay, Wis., written communication, 1993; Status codes are E, endangered, and T, threatened]

Scientific Name	Common Name	Habitat	Counties	Status
Cirsium pitcheri	Pitcher's thistle	Open sandy lakeshores, stable dunes and blowout areas	Door and Sheboygan (WI); Delta (MI)	T
Falco peregrinus	Peregrine falcon	Marshes, shores of lakes and rivers	Door, Kenosha, Milwaukee, Racine, and Sheboygan (WI); Alger, Delta, and Marquette (MI)	E
Haliaeetus leucocephalus	Bald eagle	Shores of lakes and rivers	Calumet, Door, Florence, Forest, Langlade, Marinette, Menominee, Oconto, Outagamie, Shawano, Waupaca, and Winnebago (WI); Alger, Baraga, Delta, Dickinson, Iron, Marquette, and Menominee (MI)	T
Iris lacustris	Dwarf lake iris	Partially shaded sandy-gravelly soils on lakeshores	Brown and Door (WI); Delta and Menominee (MI)	T
Oxytropis campestris	Fassett's locoweed	Open sandy lakeshores	Waushara (WI)	T
Platanthera leucophaea	Eastern prairie fringed orchid	Wet grasslands	Kenosha, Ozaukee, Waushara, and Winnebago (WI)	T
Solidago houghtonii	Houghton's goldenrod	Moist sand beach flats, and between dune ridges	Delta (MI)	T

Table A7. State-listed endangered and threatened aquatic biota of the Western Lake Michigan Drainages study area
[Data from Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Madison, Wis., written communication, 1996, and Michigan Department of Natural Resources, East Lansing, Mich., written communication, 1994; status codes are E, endangered; T, threatened]

Scientific Name	Common Name	Type	Counties	Status
Amerorchis rotundifolia	Round-leaved orchis	Plant	**MI:** Delta, Dickinson, Marquette; **WI:** Florence, Forest , Oconto, Ozaukee, Sheboygan	E (MI); T (WI)
Arenaria macrophylla	Big-leaf sandwort	Plant	**MI:** Marquette	T (MI)
Armoracia lacustris	Lake cress	Plant	**MI:** Marquette; **WI:** Brown, Green Lake, Marinette, Winnebago	T (MI); E (WI)
Asplenium viride	Green spleenwort	Plant	**MI:** Marquette; **WI:** Door, Florence	T (MI); E (WI)
Calamagrostis lacustris	Northern reedgrass	Plant	**MI:** Marquette	T (MI)
Calypso bulbosa	Calypso/Fairy-slipper	Plant	**MI:** Delta, Marquette, Menominee; **WI:** Door, Forest, Langlade, Manitowoc, Oconto	T (MI, WI)
Carex assiniboinensis	Assiniboia sedge	Plant	**MI:** Dickinson, Iron, Menominee	T (MI)
Carex atratiformis	Sedge	Plant	**MI:** Marquette	T (MI)
Carex concinna	Beautiful sedge	Plant	**WI:** Door	T (WI)
Carex crus-corvi	Crow-spur sedge	Plant	**WI:** Milwaukee	E (WI)
Carex exilis	Coast sedge	Plant	**WI:** Door	T (WI)
Carex formosa	Handsome sedge	Plant	**WI:** Brown, Milwaukee, Outagamie, Ozaukee	T (WI)
Carex garberi	Elk/Garber's sedge	Plant	**WI:** Door, Racine	T (WI)
Carex lenticularis	Shore sedge	Plant	**WI:** Manitowoc	T (WI)
Carex lupuliformis	False Hop sedge	Plant	**WI:** Kenosha, Milwaukee, Racine	E (WI)
Carex scirpoidea	Bulrush sedge	Plant	**MI:** Delta	T (MI)
Catabrosa aquatica	Brook grass	Plant	**WI:** Adams	T (WI)
Conioselinum chinense	Hemlock parsley	Plant	**WI:** Milwaukee	E (WI)
Cypripedium candidum	Small white lady's-slipper	Plant	**WI:** Fond du Lac, Green Lake, Kenosha, Marquette, Milwaukee, Outagamie, Racine, Winnebago	T (WI)
Drosera linearis	Slenderleaf sundew	Plant	**WI:** Door, Ozaukee	T (WI)
Eleocharis quadrangulata	Square-stem spikerush	Plant	**WI:** Adams, Shawano	E (WI)
Eleocharis rostellata	Beaked spikerush	Plant	**WI:** Kenosha, Racine	T (WI)
Fuirena pumila	Dwarf umbrella sedge	Plant	**WI:** Marquette	E (WI)
Geocaulon lividum	Northern comandra	Plant	**WI:** Door	E (WI)
Iris lacustris	Dwarf lake iris	Plant	**MI:** Delta, Menominee; **WI:** Brown, Door, Milwaukee	T (MI, WI)
Juncus stygius	Moor rush	Plant	**MI:** Delta, Marquette; **WI:** Florence	T (MI); E (WI)
Juncus vaysei	Vasey's rush	Plant	**MI:** Menominee	T (MI)
Myriophyllum farwellii	Farwell's water-milfoil	Plant	**MI:** Marquette	T (MI)
Nuphar pumila	Small yellow pond-lily	Plant	**MI:** Marquette	T (MI)
Oryzopsis canadensis	Canada rice-grass	Plant	**MI:** Baraga, Marquette	T (MI)
Parnassia palustris	Marsh grass-of-parnassus	Plant	**MI:** Menominee	T (MI)
Parnassia parviflora	Small-flowered grass-of-parnassus	Plant	**WI:** Door	E (WI)
Petasites sagittatus	Sweet coltsfoot	Plant	**MI:** Menominee; **WI:** Forest	T (MI, WI)

Table A7. State-listed endangered and threatened aquatic biota of the Western Lake Michigan Drainages study area—Continued

Scientific Name	Common Name	Type	Counties	Status
Plantago cordata	Heart-leaved plantain	Plant	**WI:** Brown, Kenosha, Milwaukee, Outagamie, Ozaukee, Racine	E(WI)
Platanthera flava	Pale-green orchid	Plant	**WI:** Adams, Brown, Door, Green Lake, Marquette, Milwaukee, Oconto, Portage, Waushara	T (WI)
Platanthera leucophaea	Prairie white-fringed orchid	Plant	**WI:** Kenosha, Milwaukee, Ozaukee, Racine, Sheboygan, Winnebago	E (WI)
Poa paludigena	Bog bluegrass	Plant	**WI:** Adams, Brown, Fond du Lac, Manitowoc, Marquette, Milwaukee, Oconto, Winnebago	T (WI)
Polygonum careyi	Carey's smartweed	Plant	**MI:** Iron	T (MI)
Potamogeton confervoides	Algae-like pondweed	Plant	**WI:** Forest, Langlade	T (WI)
Potamogeton vaginatus	Sheathed pondweed/ Swift-water pondweed	Plant	**WI:** Langlade, Menominee	T (WI)
Psilocarya scirpoides	Long-beaked rush	Plant	**WI:** Marquette, Waupaca, Waushara	T (WI)
Ranunculus cymbalaria	Seaside crowfoot	Plant	**WI:** Brown, Kenosha, Manitowoc, Milwaukee, Racine, Sheboygan	E(WI)
Ranunculus gmellinii	Small yellow water crowfoot	Plant	**WI:** Door, Langlade, Marinette	E (WI)
Ranunculus lapponicus	Lapland buttercup	Plant	**MI:** Delta	T (MI)
Scirpus cespitosus	Tussock bulrush	Plant	**WI:** Door, Kenosha, Racine	E (WI)
Scirpus clintonii	Clinton's bulrush	Plant	**MI:** Marquette	T (MI)
Scutellaria parvula	Small skullcap	Plant	**MI:** Menominee; **WI:** Sheboygan	T (MI); E (WI)
Thalictrum revolutum	Waxy meadow-rue	Plant	**MI:** Delta, Marquette, Menominee	T (MI)
Thalictrum venulosum	Veiny meadow-rue	Plant	**MI:** Delta, Marquette, Menominee	T (MI)
Tofieldia glutinosa	Sticky false-asphodel	Plant	**WI:** Door, Green Lake, Kenosha, Manitowoc, Marquette, Milwaukee, Racine, Waushara	T (WI)
Valeriana sitchensis	Marsh valerian	Plant	**WI:** Florence, Marinette, Outagamie, Portage, Sheboygan, Waupaca	T (WI)
Calephelis mutica	Swamp metalmark	Insect	**WI:** Fond du Lac, Marinette, Ozaukee, Washington	T (WI)
Ophiogomphus howei	Pygmy snaketail	Insect	**WI:** Florence, Forest, Langlade, Marinette, Menominee, Oconto	E (WI)
Alasmidonta viridis	Slippershell	Mollusk	**WI:** Langlade, Menominee, Oconto, Shawano, Sheboygan	T (WI)
Hendersonia occulta	Cherrystone drop	Mollusk	**MI:** Delta; **WI:** Brown, Door	T (MI, WI)
Epioblasma triquetra	Snuffbox	Mollusk	**WI:** Outagamie, Shawano, Waupaca	E (WI)
Planorbella multivolvis	Acorn rams-horn	Mollusk	**MI:** Marquette	E (MI)
Simpsonaias ambigua	Salamander mussel	Mollusk	**WI:** Langlade, Outagamie, Shawano, Waupaca	T (WI)
Tritogonia verrucosa	Buckhorn	Mollusk	**WI:** Langlade, Outagamie, Shawano, Waupaca, Winnebago	T (WI)
Venustaconcha ellipsiformis	Ellipse	Mollusk	**WI:** Fond du Lac, Manitowoc, Sheboygan, Washington	T (WI)
Acris crepitans blanchardi	Blanchard's cricket frog	Frog	**WI:** Brown, Calumet, Door, Marquette, Ozaukee, Washington, Waupaca, Waushara	E (WI)

Table A7. State-listed endangered and threatened aquatic biota of the Western Lake Michigan Drainages study area—Continued

Scientific Name	Common Name	Type	Counties	Status
Clemmys insculpta	Wood turtle	Turtle	**WI:** Brown, Florence, Langlade, Marinette, Menominee, Oconto, Outagamie, Portage, Racine, Shawano, Waupaca, Winnebago	T (WI)
Emydoidea blandingii	Blanding's turtle	Turtle	**WI:** Adams, Brown, Florence, Fond du Lac, Green Lake, Kenosha, Marinette, Marquette, Oconto, Racine, Shawano, Washington, Waupaca, Waushara, Winnebago	T (WI)
Regina septemvittata	Queen snake	Snake	**WI:** Green Lake, Milwaukee, Ozaukee, Racine, Sheboygan, Washington	E(WI)
Sistrurus catenatus	Eastern massasauga	Snake	**WI:** Portage, Racine	E (WI)
Thamnophis proximus	Western ribbon snake	Snake	**WI:** Door, Kenosha, Milwaukee, Oconto, Racine	E (WI)
Thamnophis sauritus	Northern ribbon snake	Snake	**WI:** Door, Marinette, Racine, Sheboygan, Washington	E (WI)
Acipenser fulvescens	Lake sturgeon	Fish	**MI:** Baraga, Delta, Menominee	T (MI)
Lepomis megalotis	Longear sunfish	Fish	**WI:** Brown, Fond du Lac, Kenosha, Kewaunee, Milwaukee, Oconto, Ozaukee, Racine, Shawano, Washington, Waushara	T (WI)
Luxilus chrysocephalus	Striped shiner	Fish	**WI:** Door, Kenosha, Milwaukee, Ozaukee, Racine, Sheboygan, Washington, Winnebago	E (WI)
Lythrurus umbratilis	Redfin shiner	Fish	**WI:** Brown, Fond du Lac, Kenosha, Manitowoc, Milwaukee, Oconto, Ozaukee, Portage, Racine, Shawano, Washington, Waupaca, Waushara	T (WI)
Moxostoma carinatum	River redhorse	Fish	**WI:** Kenosha, Racine, Shawano, Waupaca	T (MI, WI)
Moxostoma valenciennesi	Greater redhorse	Fish	**WI:** Brown, Calumet, Fond du Lac, Manitowoc, Marinette, Milwaukee, Oconto, Ozaukee, Sheboygan, Washington, Waupaca, Waushara, Winnebago	T (WI)
Notropis anogenus	Pugnose Shiner	Fish	**WI:** Fond du Lac, Kenosha, Kewaunee, Marquette, Racine, Shawano, Sheboygan, Washington, Waupaca, Waushara, Winnebago	T (WI)
Noturus exilis	Slender madtom	Fish	**WI:** Washington	E (WI)
Polyodon spathula	Paddlefish	Fish	**WI:** Adams, Oconto	T (WI)
Buteo lineatus	Red-shouldered hawk	Bird	**MI:** Delta, Iron; **WI:** Adams, Door, Florence, Forest, Green Lake, Langlade, Manitowoc, Marinette, Marquette, Menominee, Milwaukee, Oconto, Ozaukee, Portage, Racine, Shawano, Sheboygan, Washington, Waupaca	T (MI, WI)

Table A7. State-listed endangered and threatened aquatic biota of the Western Lake Michigan Drainages study area—Continued

Scientific Name	Common Name	Type	Counties	Status
Casmerodius albus	Great egret	Bird	**WI:** Fond du Lac, Green Lake, Kenosha, Manitowoc, Outagamie, Portage, Shawano, Sheboygan, Washington, Waupaca, Waushara, Winnebago	T (WI)
Charadrius melodus	Piping plover	Bird	**WI:** Door, Kenosha, Manitowoc, Oconto, Sheboygan	E (WI)
Dendroica cerulea	Cerulean warbler	Bird	**WI:** Door, Forest, Green Lake, Manitowoc, Marinette, Washington	T (WI)
Empidonax virescens	Acadian flycatcher	Bird	**WI:** Green Lake, Manitowoc, Washington	T (WI)
Falco peregrinus	Peregrine falcon	Bird	**MI:** Delta, Marquette; **WI:** Brown, Door, Green Lake, Manitowoc, Milwaukee, Ozaukee, Waupaca	E (MI, WI)
Gavia immer	Common loon	Bird	**MI:** Baraga, Delta, Dickinson, Iron, Marquette	T (MI)
Haliaeetus leucocephalus	Bald eagle	Bird	**MI:** Baraga, Delta, Dickinson, Iron, Marquette, Menominee; **WI:** Adams, Florence, Forest, Langlade, Marinette, Menominee, Oconto, Outagamie, Portage, Shawano	T (MI, WI)
Pandion haliaetus	Osprey	Bird	**MI:** Baraga, Delta, Dickinson, Iron, Marquette; **WI:** Adams, Forest, Green Lake, Langlade, Manitowoc, Marinette, Portage	T (MI, WI)
Podiceps grisegena	Red-necked grebe	Bird	**WI:** Fond du Lac, Oconto, Winnebago	E (WI)
Rallus elegans	King rail	Bird	**MI:** Marquette	T (MI)
Sterna caspia	Caspian tern	Bird	**MI:** Delta; **WI:** Brown, Oconto, Winnebago	T (MI) E (WI)
Sterna forsteri	Forster's tern	Bird	**WI:** Adams, Brown, Green Lake, Kenosha, Manitowoc, Marinette, Marquette, Oconto, Winnebago	E (WI)
Sterna hirundo	Common tern	Bird	**MI:** Delta; **WI:** Brown, Fond du Lac, Manitowoc, Marinette, Oconto, Winnebago	T (MI) E (WI)