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# Conservation Guidelines for Michigan Lakes and Associated Natural Resources

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**and**
**Gregory J. Soulliere**

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# Conservation Guidelines for Michigan Lakes and Associated Natural Resources

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*Abstract*–The Michigan Department of Natural Resources, Fisheries and Wildlife divisions, have developed guidelines for protecting and restoring the natural resources of Michigan lakes. These guidelines follow the department's ecosystem-based approach to natural resource management that combines ecological, social, and economic considerations toward achieving the goal of conserving and sustaining natural resources. The guidelines were developed to support department staff in managing public trust lake resources, and also as reference information for other organizations and individuals interested in Michigan lakes. Background material provided includes descriptions of basic ecological features and processes of lakes, important natural resources including habitat requirements, and lists of aquatic plants, mollusks, crayfish, amphibians, reptiles, birds, and mammals that reside in Michigan lakes. Descriptions of stresses and threats to lake ecology include the cumulative effects of small modifications to habitats, artificial drainage, water quality and pollutants, dams and lake-level control, non-indigenous species, shoreline development, dredging and filling bottomlands, vegetation alteration, swimmer's itch control, and boating and shipping activities. The guidelines recommend a watershed approach for protection and management of ecosystem integrity and natural resources of lakes, with development of comprehensive resource assessments and management plans.

## Introduction

The Michigan Department of Natural Resources (DNR) is responsible for managing fish and wildlife populations and their habitats, thus protecting the public trusts in these resources in Michigan. Among these resources, lakes are some of the most productive and biologically diverse ecosystems that exist. A vast array of aquatic organisms including plants, crayfish, fish, mollusks, and amphibians, as well as many reptiles, birds, and mammals, depend on lakes and their associated wetlands and uplands for survival. However, most lakes in Michigan, including the Great Lakes, have been subjected to

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significant biological and ecological changes as a result of human influences. These changes can degrade lake quality, resulting in losses of fish and wildlife species, lost recreational opportunities for citizens, and, ultimately, a lower quality of life for Michigan residents.

Michigan has an obligation to preserve and protect its resources as prescribed by Article 4, § 52 of the Michigan Constitution. The Michigan Legislature has implemented this constitutional mandate by establishing the Michigan Department of Natural Resources (Natural Resources and Environmental Protection Act, 1, Act 451, Part 5, § 324.501), and established duties for the department (Act 451, Part 5, § 324.503):

> The department shall protect and conserve the natural resources of this state; provide and develop facilities for outdoor recreation; …prevent and guard against the pollution of lakes and streams within the state and enforce all laws provided for that purpose with all authority granted by law; and foster and encourage the protection and propagation of game and fish. The department has the power and jurisdiction over the management, control, and disposition of all land under the public domain, except for those lands under the public domain that are managed by other state agencies to carry out their assigned duties and responsibilities.

Under the public trust doctrine, Michigan holds all fish, amphibians, reptiles, mussels, mammals, birds, and other wildlife in trust for the benefit of the people of Michigan.

There are many factors that the DNR must consider in fulfilling its obligations under the public trust doctrine. This is especially true for Michigan lakes. Human developments in and around lakes continue to increase and alterations to fish and wildlife habitat are also expanding. Both commercial and residential land uses are significant factors influencing lake management, including activities related to home and septic tank construction, dredging and filling of bottomland (including beach sanding), dock and marina construction, shipping on the Great Lakes and connecting waterways, artificial lake levels maintained by dams, and removal of vegetation within and around the lake. Michigan lakes are used by many recreational interests in addition to lakeshore property owners (riparians). Swimming, boating, sunbathing, relaxation, scuba diving, sightseeing, fishing, hunting, trapping, and wildlife viewing are some of the reasons people are attracted to lakes.

A goal of the DNR is to promote optimum recreational use of public trust resources for Michigan citizens. However, with such highly diverse interests and activities associated with Michigan lakes, this can be a difficult goal to reach. Lake alterations prescribed to improve one type of recreational use often reduce the system's ecological integrity or recreational opportunities for other users. Conservation of biodiversity and ecological integrity require planning and management when alterations are proposed to a lake system. A thorough knowledge of, and proper planning for lake resources management will help to insure that ecological integrity is conserved and that sustainable populations of fish and wildlife remain available for current and future generations of Michigan citizens.

Natural resource managers, regulators, and private citizens often have different viewpoints on lake conservation issues due to different training, experience, and personal values. The guidelines provided in this document were developed to assist lake stakeholders in understanding and incorporating the scientific principles of ecosystem management into decisions that will influence Michigan lakes. Stakeholders with varying interests must understand the importance of maintaining the ecological integrity of lakes and maintaining the natural diversity and abundance of plants and animals, while remembering that social needs and recreational pursuits are part of ecosystem management.

Information in this document: (1) identifies the general goals of the Michigan DNR fisheries and wildlife management programs, (2) provides a brief description of the ecosystem features of watersheds and lakes used in management assessments and planning, (3) reviews the most common stresses and threats to Michigan lakes, and (4) provides guidelines for resource conservation of lakes and associated wetland communities.

## Natural Resources of Lakes and Management Considerations

The animal and plant resources associated with Michigan lakes are vast and provide significant recreational benefits, commercial benefits, and ecological services for the citizens of the state. In 2001, there were an estimated 16.6 and 0.6 million days of fishing and migratory bird hunting at lakes, with associated economic values of $712.3 million and $39.1 million (U.S. Department of the Interior 2002). An estimated 1.1 million people participated in wildlife viewing away from home (non-residential) and associated with a waterbody; this wildlife viewing had an estimated value of $276.4 million. These values do not include the many other recreational and commercial uses of lakes.

Fish, mammals, and birds are often the focus of natural resource users and management considerations. However, algae, higher aquatic plants (aquatic macrophytes), and numerous species of small animals form the base of the food chain, and the plants provide habitat necessary to support lake ecosystems. Many species of plants and animals found in lakes are severely reduced in abundance compared with historical levels. This trend suggests diminished ecological integrity of lakes and loss of biodiversity that may affect the continued viability of fish and wildlife species associated with Michigan lakes.

The Michigan Natural Features Inventory presently lists 2,279 higher plant species found in Michigan (Penskar et al. 2001). Approximately 41% of these may be found growing on water-saturated soils. Approximately 18% (499 obligate wetland species) have a greater than 99% probability of growing in water or on saturated soils (Appendix 1). The obligate wetland species include 38 non-indigenous species, 10 extirpated species, and 92 species that are threatened, endangered, or of special concern. Of the 499 obligate species, 141 species grow submerged in water or have floating-leaves, including 8 non-indigenous species, 2 extirpated species, and 24 species that are threatened, endangered, or of special concern. The remaining obligate species grow with part of the plant below the water and the remaining portion emerging above the water (emergent plants), or grow on saturated soils with no standing water.

Mollusks, crayfish, and fish live within the waters of lakes. Michigan has 121 species of mussels and snails that live in lakes including 10 non-indigenous species and 9 threatened, endangered, or special concern species (Appendix 2). There are 7 species of crayfish including one non-indigenous species (Appendix 3). Lakes in Michigan contain 154 species of fish, including 25 non-indigenous species and 23 species that are threatened, endangered, or of special concern (Appendix 4). Five species have been extirpated and are extinct.

Many amphibians, reptiles, birds, and mammals require or use Michigan lakes. Twenty-four species of amphibians (Appendix 5) and 25 species of reptiles (Appendix 6) use Michigan lakes, including 4 amphibian and 8 reptile species that are threatened, endangered, or of special concern. Birds (Appendix 7) and mammals (Appendix 8) may require lake environments all or part of the year. There are 87 species of birds and 19 species of mammals commonly associated with Michigan lakes.

The ecosystem-based approach to natural resources management combines ecological, social, and economic considerations toward achieving the goal of conserving and sustaining natural resources. This management process forms a comprehensive strategy aimed at protecting and enhancing sustainability, diversity, and productivity of natural resources. The Ecological Society of America described eight elements of ecosystem management (Christensen et al. 1996a) that have been endorsed by the Michigan Department of Natural Resources:

1. Ecosystem management regards intergenerational sustainability as a precondition.
2. Ecosystem management establishes measurable goals for sustained resources.
3. Ecosystem management relies on research performed at all levels of ecological organization.
4. Ecosystem management recognizes that biological diversity and structural complexity strengthen ecosystems against disturbance and supply the genetic resources necessary to adapt to long-term change.
5. Ecosystem management avoids attempts to freeze ecosystems in a particular state of configuration, because change and evolution are an inherent component.
6. Ecosystem processes operate over a wide range of spatial and temporal scales, and their behavior is greatly influenced by surrounding systems. Thus, there is no single appropriate scale or time frame for management.
7. Ecosystem management values the active role of humans in achieving sustainable management goals.
8. Ecosystem management acknowledges that current knowledge of ecosystem functions are provisional and subject to change. Management approaches must be viewed as hypotheses to be tested by research and monitoring programs.

Listed below are several Department of Natural Resources general fisheries and wildlife goals important to management of lake resources in Michigan. These goals are included in the Strategic Plans for Fisheries and Wildlife divisions:

- Ensure that Michigan’s fish and wildlife are managed to maintain viable populations within healthy, sustainable ecosystems.
- Provide a variety of opportunities for fishing, hunting, trapping, and other forms of related recreation, education, observation, and appreciation.
- Identify, restore, conserve, and protect natural communities and associated threatened and endangered species.
- Foster and contribute to public stewardship of natural resources through a scientific understanding of fish, fishing, and fisheries management.
- Provide information and educational assistance to enable people to understand and appreciate wildlife, wildlife habitats, natural resource management, and human-wildlife interactions.
- Continuously improve natural resources conservation through scientific research, employee education and training, open public participation, and responsive management.
- Help ensure that Michigan’s natural resources are managed through a cooperative, ecosystem-based approach involving both public and private partners.
- Permit and encourage economically efficient and stable commercial fisheries that accommodate Native American fishing rights and do not conflict with recreational fisheries.

Other agencies have responsibilities associated with protecting natural resources in Michigan waters. These include several federal agencies and the Michigan Department of Environmental Quality. The federal government has regulatory authority over dredging and filling activities in federally navigable waters, generally including the Great Lakes, various rivers, and inland lakes connected to the Great Lakes. In 1994, many regulatory responsibilities of the Department of Natural Resources were transferred to the newly created Department of Environmental Quality under the Natural Resources and Environmental Protection Act, Public Act 451. Some of these responsibilities included regulation of surface water quality, dredging and filling activities in lakes and wetlands, and regulation of the aquatic nuisance control program (aquatic plants and swimmer’s itch).

Part 309 of Public Act 451 allows the establishment of lake boards. With participation from local governing bodies, lake boards may make lake improvements. Lake improvements may be made in lakes or adjacent wetlands, and lake boards may take steps necessary to remove undesirable accumulated materials from the bottom of a lake or wetland by dredging, ditching, digging, or related work. Special assessment districts can be established to provide funding for lake improvement projects. Part 307 of Public Act 451 allows a county board to petition the court to establish an artificial, regulated inland lake-level (create a dam). Special assessment districts may be established to provide funding for normal inland lake-level projects.

Other stakeholder groups also affect or influence natural resource management of Michigan lakes. Typical groups include watershed councils, fishing and hunting organizations, environmental groups, and lake associations.

## Characteristics of Michigan lakes

Michigan lakes vary in size from the very large Great Lakes to very small bodies of water. Some may contain water only periodically, such as vernal ponds. Some lakes are isolated, having no tributaries or outlet streams, with small watersheds. Lakes with tributary streams generally have larger watersheds, some of which encompass the largest river watersheds in the state. The Great Lakes collect all tributaries of the state and have very extensive watersheds.

Michigan's political boundary encompasses an area of 96,791 $mi^2$ (Sommers 1977), with roughly 40% (38,575 $mi^2$) covered by the Great Lakes, and over 1,300 $mi^2$ (1.3%) covered by inland lakes. There are 62,798 inland lakes with a surface area of at least 0.1 acres or larger, 1,148 lakes exceeding 100 acres, 98 lakes exceeding 1,000 acres, and 10 lakes over 10,000 acres (Breck 2004). Houghton Lake is the largest inland lake in the state, encompassing 20,044 acres. The Great Lakes rank among the 15 largest lakes in the world and contain about one-fifth of the world's supply of fresh water. The Great Lakes contain 95% of the surface freshwater in the United States. Lake Superior is the largest of the Great Lakes with a maximum depth of 1,333 feet and it contains over 50% of the water in the Great Lakes (Michigan State University 1987).

This document focuses on lakes and areas immediately adjacent to lakes (riparian areas). Various ecological zones are typically used to describe areas within and adjacent to lakes. Each zone provides habitat (or partial habitat) for many organisms. These zones include the pelagial, profundal, littoral, and the upland portions of the lake's watershed (Figure 1). The pelagial zone is the open water area of the lake. The profundal zone lies below the pelagial zone and includes the bottom area where rooted plants do not grow. The littoral zone delineates the area of the lake where rooted aquatic plants (macrophytes) grow (maximum of 5–25 feet deep depending on the lake) shoreward to where the land is unaffected by lake water at the high water mark. The lake's watershed may contain various types of wetlands, other lakes, groundwater sources, and tributary streams. The shoreline or riparian area of a lake is a transition zone between the lake and uplands, and is also referred to as the shoreline ecotone. All of these zones include habitat components for organisms dependent on the lake to survive or reproduce.

Lakes form in many ways and their geomorphology plays a significant role in the ecological functioning of individual systems. The study of lake features, such as the shape of the basin and type of sediment on the bottom, is known as lake morphology. Much of the way a lake functions, including its recreational potential, can be deduced from the lake's morphology. Most of the natural lake depressions in Michigan resulted from glacial activity. Many are called "kettle" lakes, formed by the melting of remnant blocks of ice that had been buried in glacial till deposits. Some formed from glacial scouring. A relatively small number of lakes, known as "karst" lakes, were formed by the dissolution of sedimentary rock. Some natural impoundments were formed by earth movements blocking stream channels. Beaver continue to create and abandon many small impoundments on streams, especially across the northern two-thirds of the state. Humans have formed many unnatural impoundments and reservoirs through purposeful damming of rivers. Reservoirs, by definition, have 50% or greater of their maximum depth maintained by a man-made dam. It is important to understand the processes that formed the lake in order to deduce how the lake and surrounding landscape should function.

Glacial terrain is characterized by a landscape of hills and depressions. Lakes can be present in many different parts of the landscape and can have complex surface and ground-water flow systems associated with them. Although rivers often drain parts of these landscapes, many areas of glacial terrain do not contribute runoff to rivers. Instead, surface runoff from precipitation falling on the landscape accumulates in these depressions, contributing to the presence of a lake. Because of the lack of stream outlets, the water balance of these "closed" types of lakes and wetlands is controlled largely by precipitation, evaporation, and ground water. The interaction between a lake and its ground water supply usually cannot be observed and is therefore more difficult to understand. It is determined to a large extent by the lake's position with respect to local and regional ground-water flow systems. Lakes interact with ground water in three basic ways: some receive ground-water inflow throughout their entire bed; some have seepage loss to ground water throughout their entire bed; but perhaps most lakes receive groundwater inflow through part of their bed and have seepage loss to ground water through other parts. Lake sediments often have significant organic, relatively impermeable deposits that affect the exchanges of water, minerals, and nutrients.

Bathymetric maps provide details about the terrain, or shape, of the lake's underwater landscape. A bathymetric map can be used to calculate several measurements that are crucial to understanding how the lake system functions, including surface area, volume, maximum length, mean width, maximum width, mean depth, maximum depth, shoreline length, shoreline development, slope of the bottom, and proportion of the basin in littoral and profundal zones.

Surface area is one of the most important morphological parameters of a lake because it not only describes the size of a lake, but also plays a major role in lake function. Bottom slope helps in predicting how a lake's surface area will be affected with changing water levels. Lake surface area can also be used to help predict the potential effects of wind on a lake. In general, lakes with more surface area are subject to larger waves during windy conditions which can result in extensive shore erosion. This is significant because larger waves have the ability to mix water at greater depths, in some instances reaching all the way to the bottom of the lake. The ability to create mixing at the bottom of a lake is extremely important because it can result in the re-suspension of sediments and the disturbance of submersed aquatic plants. Thermal stratification can also be prevented, affecting the level of oxygen present in bottom waters. As a result, other lake characteristics, such as water clarity and the availability of nutrients, can be affected.

Shoreline development refers to the length of a lake's shoreline relative to the length of the circumference of a circle of area equal to that of the lake. In other words, lakes with longer, irregularly shaped shorelines are considered to have more shoreline development, while circular lakes are considered to have less. (The use of the term development here does not refer to such human developments as cottages or seawalls, but rather to the shape of a lake's shoreline). Determining a lake's shoreline development is important because it reflects the potential for greater development of littoral communities in proportion to the surface of the lake. A greater amount of natural shoreline development provides more interface between the water and surrounding land (i.e., coves and peninsulas), often translating into more habitat for fish, birds, and other wildlife to raise their young. Irregular shorelines also absorb more wave energy and provide better substrates for plant growth.

Maximum length and width measurements are also important because they can be used to determine fetch, or the distance that wind can travel over water before intersecting a landmass. Fetch distances can be used to predict the depth at which wave energy extends below the water's surface since the greater the fetch distance, the greater potential there is for large waves. Longer fetch and higher wind speed both create greater wavelengths and wave heights. The depth of wave impact can be estimated from the fetch distance and wind speed.

Large beds of aquatic plants can also alter sedimentation patterns in a lake in several ways. The plants themselves greatly reduce the amount of turbulence within the plant beds, resulting in an accumulation of fine particles in shallow areas that are dominated by plants. This can happen even though there may be deep areas within the lake. Plant beds can moderate the development of waves in a lake. Thus, shallow lakes filled with plants may not develop large waves and the fine sediments will be protected from re-suspension. Such plant-dominated lakes tend to appear clear due to a lack of turbulence that would otherwise keep fine particles and algae in suspension. Aquatic plants can significantly reduce erosion of the shoreline by waves.

The terms lacustrine and lentic are also used to describe lakes or water bodies that have still waters. Shallow lakes include basins that have never been preceded by a larger, deeper lake, and those basins that represent the terminal stages of deep lakes that have filled with sediment. Shallow water bodies can be separated into those that are permanent, containing some water at all times of the year, and those that are temporary, in which the basin periodically has no standing water (Wetzel 1975; Figure 2). Vernal lake, swamp, marsh (fen), bog, mire (bog or fen), and wetland are terms that have been used to describe shallow lakes or the shallow portions of lakes.

Wetlands have received significant attention in natural resource disciplines during recent years because of their importance to the ecological integrity of natural systems, and the significant losses of wetlands that have occurred through artificial drainage and filling activities. Classifications of wetlands have been made to aid in inventory, evaluation, and management (Cowardin et al. 1979). The broadest classification includes five systems: marine, estuarine, riverine, lacustrine, and palustrine. Only the latter three apply in Michigan. Numerous subsystems, classes, subclasses, and dominance types are used in classifying wetlands. Generally, wetland types are classified using floral characteristics, composition of substrate, water regime, and water chemistry. There are also specific legal definitions of wetlands for regulatory purposes. The portion of a lake that typically is referred to as a wetland includes the areas of the littoral zone containing emergent vegetation, normally at depths of 5 feet or less. The remaining portions are referred to as "deepwater habitats" in wetland classification systems, although the term "submerged wetland" is sometimes used to describe the portion of the littoral zone with submerged plants. Lakes always contain some wetlands, and sometimes lakes are entirely wetlands when emergent vegetation grows throughout the lake. In lacustrine systems, wetlands are often significantly affected by human development. This occurs because wetlands predominantly occur along the shoreline where most development occurs.

## Ecological features and processes of lakes and wetlands

Lakes are complex ecosystems defined by all system components affecting surface and ground water gains and losses. This includes the atmosphere, precipitation, geomorphology, soils, plants, and animals within the entire watershed, including the uplands, tributaries, wetlands, and other lakes. Management from a whole watershed perspective is necessary to protect and maintain healthy lake systems. This concept is important for managing the Great Lakes as well as small inland lakes, even those without tributary streams. A good example of the need to manage from a whole watershed perspective is the significant ecological changes that have occurred in the Great Lakes. The Great Lakes are vast in size, and it is hard to imagine that building a small farm or home, digging a channel for shipping, fishing, or building a small dam could affect the entire system. However, the accumulation of numerous human development activities throughout the entire Great Lakes watershed resulted in significant changes to one of the largest freshwater lake systems in the world. The historic organic contamination problems, nutrient problems, and dramatic fisheries changes in our Great Lakes are examples of how cumulative factors within a watershed affect a lake.

Habitat refers to an area that provides the necessary resources and conditions for an organism to survive. Because organisms often require different habitat components during various life stages (reproduction, maturation, migration), habitat for a particular species may encompass several cover types, plant communities, or water-depth zones during the organism's life cycle. Moreover, most species of fish and wildlife are part of a complex web of interactions that result in successful feeding, reproduction, and predator avoidance. Seemingly minor physical changes in a portion of a lake or neighboring upland watershed can disrupt the system and significantly influence species diversity and abundance of plants and animals within the lake ecosystem.

### *Water Quality*

The quality of lake water depends on a variety of factors including the underlying geologic formations, landforms, soils, precipitation, evaporation, ratios of ground water to surface water drainage, and human influences caused by alteration of the landscape (Figure 3). These factors determine the inorganic and organic chemical constituents of lake water. Important components of water quality include phosphorous, nitrogen (ammonia, nitrate, and nitrite), water temperature, oxygen, carbon dioxide, pH, and a number of metals and salts. Typical water quality values for Upper Peninsula and northern Lower Peninsula Michigan lakes collected in 1984 are provided in Table 1.

Water temperature influences internal structure, chemistry, biological metabolism, and the types of aquatic organisms that live in lakes. Water temperatures in Michigan lakes vary from the southern portion of the state to the northern portion, a function of regional air temperatures. Internal lake water temperatures also vary. The warmest water temperatures are found near the surface of the lake (epilimnion) during summer months and near the bottom of the lake (hypolimnion) during winter months. This condition is called stratification. Stratification is most pronounced during summer months when temperature changes are the greatest. A zone of rapid temperature change occurs in the metalimnion (also called thermocline, generally 15–40 feet deep; Figure 4), and this often forms a physical barrier that prevents interchange of water, gases, organic material, and nutrients between the epilimnion and the hypolimnion. In spring and autumn, water temperatures become uniform throughout the water column for a period of time and these are referred to as “turnover periods.” Turnover periods are important in the cycling of organic matter and chemicals, especially nutrients, in many lakes. Stratification varies annually depending on solar radiation, wind, and the physical features of each lake. Shallow lakes often do not stratify and have relatively uniform water temperatures throughout the water column. Aquatic vegetation can affect water temperatures in the littoral zone. Shading by plants can create cooler water temperature microhabitats in the littoral zone that influence the distribution of aquatic organisms.

Michigan Surface Water Quality Standards (MAC R323.1041 – R323.1117 promulgated pursuant to Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994, PA 451, as amended) provide water temperature limits for water discharges into lakes. These standards allow not more than a 3°F temperature increase at the edge of a discharge mixing zone in all lakes. The Great Lakes and inland lakes also have specific monthly temperature limits in various parts of the state.

Dissolved oxygen is important for sustaining aquatic life. The solubility of oxygen and other gases depend on water temperature. Colder water can contain more dissolved gases. Oxygen enters the water from the atmosphere and it is produced by aquatic plants during photosynthesis. Oxygen is used by all animals and microorganisms in lakes and it is removed by plants during respiration when sunlight is not available. Oxygen depletion can occur in lakes with high plant and animal oxygen demand, especially in areas of lakes where waters do not mix freely or come in contact with the atmosphere. Water quality standards (related to discharges) in Michigan require maintenance of 7 mg/l dissolved oxygen for all Great Lakes and connecting waters, designated trout streams, and coldwater inland lakes. The water quality standard for other water bodies is 5 mg/l. Minimum dissolved oxygen levels for suitable summer habitat are approximately 3.0 mg/l for coldwater and coolwater fish and 2.5 mg/l for warmwater fish (Schneider 2002). The influence of water temperature stratification, dissolved oxygen, and trophic status determine the types of aquatic organisms that live in a lake, and are discussed later under trophic status.

The carbon dioxide content of lakes is affected by photosynthesis, respiration, and contact with the atmosphere. It is the basic carbon source from which plants produce sugar and more complex organic matter and is therefore a vital component of lake chemistry.

Alkalinity, hardness, and pH are measures of acidity and the buffering capacity of water. The acidity (hydrogen ion concentration) of water is measured by pH. A lower pH value indicates higher acidity. Alkalinity is a measure of the carbonate levels or acid buffering capacity in water. Buffering capacity increases with increasing alkalinity. Hardness is a measure of calcium and magnesium levels. Alkalinity and hardness generally are associated through calcium and magnesium carbonate reactions. High hardness generally indicates high alkalinity. Typical ranges of these parameters are listed in Table 2. A pH of 7 is neutral, and a pH of 3 or less is toxic to most fish. Species vary in their sensitivity to pH. The pH of most lakes ranges between 6 and 9. Hardwater lakes commonly are buffered strongly and have pH values above 8. Seepage lakes and lakes with an igneous rock catchment are less well buffered and may have pH values somewhat less than 7. Bog lakes typically have pH values of 3 to 5. Generally, hardwater lakes are more productive than softwater lakes because more inorganic carbon is available for photosynthesis. The majority of softwater lakes are in the Upper Peninsula. Underlying geological formations of the Lower Peninsula are predominantly deep glacial deposits over limestone bedrock, while much of the Upper Peninsula has a thin layer of glacial deposits underlain by igneous rock.

Chlorides, sulfate, sodium, and potassium generally are indicators of pollution or excessive drainage and runoff from the watershed. Generally these elements and their compounds are low in natural lakes. Typical land uses associated with these chemical constituents include septic tanks, polluted rainwater, road salting, animal waste, and fertilizer.

Trace metals are important to both human and animal health. In general, metals usually are not found at significantly elevated levels in lakes unless pollution was discharged into the lake. Most of these sites have been identified. Elevated mercury levels are found in many species of fish in Michigan lakes, resulting in general statewide consumption advisories. It is generally accepted that atmospheric inputs of mercury are the primary cause of the elevated mercury levels.

Phosphorous is an important nutrient for plant growth and most often is the limiting nutrient for plant growth in lakes. Naturally productive lakes have higher levels of phosphorous in the soils of the catchment than unproductive lakes. Human land-use practices presently are the principal source of phosphorus for most Michigan lakes. Phosphorous does not dissolve easily in water and forms insoluble precipitates with calcium, magnesium, and iron. This makes phosphorous less available for algal growth. These precipitates accumulate in the sediments where rooted aquatic macrophytes may extract the phosphorous. Hardwater lakes may have low algae and clear water with abundant macrophyte growth. When oxygen is not present, iron compounds release phosphorous to the water. This is an important mechanism for seasonal phosphorous recycling within deeper, stratified lakes.

Nitrogen is second only to phosphorous as a nutrient for plant growth. Nitrogen occurs in various forms in lakes. These forms include ions of nitrate ($NO_3^-$), nitrite ($NO_2^-$), ammonium ($NH_4^+$), and organic compounds. Total nitrogen is determined by adding nitrate, nitrite, and Kjeldahl (organic plus ammonium) nitrogen. Rain can be a source of nitrogen for lakes, but human land-use practices presently are the principal source in Michigan lakes. Nitrogen can be the limiting nutrient for algal growth when the ratio of total nitrogen to total phosphorous is less than 10:1. Phosphorous is the limiting nutrient at values greater than 15:1. Nitrogen may be a factor in limiting rooted aquatic plant growth. It may also affect species composition and influence non-indigenous plant growth.

Transparency and chlorophyll-*a* are measures of productivity. Transparency, or water clarity, is measured visually using a Secchi disk (a 20–cm weighted white disk). Lower transparency generally indicates higher algal production in lakes. Chlorophyll-*a* is a component of the cells of most plants. High chlorophyll-*a* levels indicate high levels of algal growth and productivity in the water.

### *Trophic State*

Several ecological processes are common to biological communities. Energy flow in food webs is initiated by photosynthesis and the rate of photosynthetic energy transfer is influenced by climate, nutrient cycling, hydrology, and succession. Natural and human-related disturbances can dramatically influence the energy flow process (Schindler and Scheuerell 2002). All components of a drainage basin influence the regulation of lake metabolism. Natural components of the watershed that influence the composition and production of the biotic community of a lake include the chemical composition of the water (including nutrients), the flow of water through the lake, organic inputs, and the morphometry of the lake basin. Other factors contributing to biological productivity include animal food (trophic) relations with plants and other animals and the competitive and predatory interactions that lead to greater success of one species over another.

The trophic state of a lake refers to the rate of organic matter supply and is a measure of its productivity. Generalized mechanisms regulating the trophic status of lakes are presented in Figure 5. Oligotrophic lakes are low in productivity and eutrophic lakes are high in productivity. Mesotrophic lakes have intermediate levels of productivity. Rates of productivity are regulated by natural and human-induced levels of carbon and inorganic nutrient inputs into the lake. Typical levels of phosphorous, chlorophyll-*a*, and transparency are provided in Table 3.

Oligotrophic lakes are typically deep with a relatively large hypolimnion and low biological productivity. They have clear water, with Secchi disk transparency readings of 15 feet or greater. Nutrients concentrations are low, with phosphorous concentrations generally less than 0.010 mg/l. Aquatic macrophyte populations are generally sparse, with some dense stands in scattered locations. Algal production is relatively low and chlorophyll-*a* concentrations remain below 0.002 mg/l. Organic matter deposition into the hypolimnion is low, keeping microbial decomposition rates and oxygen use low. The hypolimnion remains aerobic, limiting nutrient recycling within the lake. These lakes have low biological diversity and usually support coldwater and coolwater fish populations. Typical coldwater fish include lake trout, lake whitefish, lake herring, burbot, and sculpins. Typical coolwater fish include smallmouth bass, rock bass, walleye, northern pike, lake chub, and emerald shiner.

Mesotrophic lakes are moderately productive, with Secchi disk transparencies of 6 to 15 feet. Phosphorous concentrations range between 0.010 mg/l to 0.030 mg/l. Aquatic plants occur at moderate levels, with dense stands common. Large algal blooms generally do not occur, especially blue-green algal blooms. Chlorophyll-*a* concentrations range between 0.002 mg/l and 0.010 mg/l. Oxygen depletion in the hypolimnion usually occurs in late summer and winter. Some recycling of nutrients from the sediments occurs during spring and fall turnovers. These lakes support coolwater and warmwater fish populations. Typical warmwater fish include largemouth bass, bluegill, black crappie, grass pickerel, channel catfish, longnose gar, bullheads, gizzard shad, and fathead minnow. Warmwater lakes typically are dominated by centrarchid fish communities.

Eutrophic lakes have Secchi disc transparencies usually less than 6 feet. Nutrient levels are high, with phosphorous concentrations greater than 0.030 mg/l. Aquatic macrophytes may be abundant in shallow waters. Significant algal blooms, including blue-green algae, may occur. Algae may limit light and restrict the depth distribution and abundance of macrophytes. Chlorophyll-*a* concentrations are usually greater than 0.010 mg/l. High organic matter deposition in the hypolimnion results in oxygen depletion for much of the year. Anaerobic conditions promote nutrient recycling from the hypolimnion and lower rates of organic matter deposition. Shallow eutrophic lakes frequently have extensive mortalities of fish during winter months ("winterkill"). This results from oxygen depletion under ice and snow cover. Eutrophic lakes are characterized by warmwater fish populations.

Marl lakes are categorized differently in that they generally are very unproductive, yet they may have summer-time depletion of dissolved oxygen in the bottom waters and very shallow Secchi disk depths, particularly in the late spring and early summer. Groundwater entering these lakes contains dissolved $CaCO_3$ that has been acquired from limestone in the soils. Chemical reactions within the lake allow the formation of particulate calcium compounds (marl) that form deposits on the bottom and can make the water have a white, turbid appearance.

Bogs, also called dystrophic lakes, have low production of phytoplankton. The production of organic matter within bogs is predominately by littoral plants. Bogs develop through the colonization and establishment of mosses, especially *Sphagnum*, as one of the dominant plants in the littoral zone, under low nutrient and humid conditions. This can occur in both shallow and deep lakes. The mosses increase the acidity of the system, resulting in decreased rates of organic matter decomposition within the water and in accelerated filling of the lake with organic matter.

The trophic state of a lake can naturally change over time. A lake can become more or less eutrophic as natural weathering processes and nutrient fluxes in the watershed change. Generally, once the surface soils of a drainage basin have undergone weathering for an extended period, nutrient inputs decline and become relatively stable. Lakes in Michigan are highly variable in trophic status between oligotrophic and extremely eutrophic. Human development tends to increase (cultural) eutrophication in our lakes through increased surface drainage, soil erosion, vegetation and wetland removal, and nutrient additions. Many lakes in Michigan, including the Great Lakes, have increased eutrophication resulting from human activities. This primarily results from increased nutrient concentrations in lake waters resulting from pollution. Historical industrial and municipal wastewater discharges into lakes were often poorly regulated and resulted in severe eutrophication, often allowing survival of only the most tolerant fish species, such as common carp and bullheads. Presently, non-point source nutrient pollution affects a significant number of lakes. Septic tanks, lawn and agricultural fertilizers, and animal waste are typical sources. In 1982, the Michigan Department of Natural Resources surveyed 656 inland lakes and found 12% to be oligotrophic, 62% mesotrophic, and 26% eutrophic (Michigan State University 1987). The majority of Michigan's eutrophic lakes were located in the southern part of the Lower Peninsula where agriculture, urban development, and lakeshore development were prevalent. An evaluation of 91 lakes in 2002 indicated the productivity of 25% were low, 62% moderate, 12% high, and 1% excessive (Harrison 2003). In 1996, Lake Superior was classified oligotrophic, Lake Huron was oligotrophic (except for the eutrophic Saginaw Bay), Lake Michigan was oligotrophic to mesotrophic, and Lake Erie was mesotrophic except for the western basin which was eutrophic (Bredin 1998).

### *Uplands, Including the Shoreline Ecotone*

The uplands of the watershed include all of the landscape contributing surface water and groundwater drainages to the lake. Precipitation, geology, soils, and landscape morphology determine the drainage patterns, flow rates, and chemical composition of drainage waters. Forests, fields, lakes, swamps, marshes, and streams moderate surface drainage, chemical composition, and organic matter flow through the system.

The uplands of lake watersheds affect productivity of lakes through nutrient and organic matter inputs. Generally lakes with large watersheds are more productive. Watersheds rich in nutrients will naturally result in productive lakes. Organic matter, especially the dissolved forms, is an important contribution of the uplands affecting lake productivity.

The zones immediately adjacent to the lake are important transition areas between land and water, and are also referred to as ecotones and riparian areas. Riparian areas supply both particulate organic matter for the food web through leaf deposition, and large deadwood (Christensen et al. 1996b; Guyette and Cole 1999), important as a long-term carbon source and as cover for aquatic organisms. The shoreline ecotone provides critical habitat components for most amphibians, reptiles, mammals, and birds that require or use lacustrine systems. Seasonal and diurnal movements between various habitat components within the shoreline ecotone are necessary for survival of many animals. Management and maintenance of natural riparian areas is very important to the ecological integrity of lakes.

### *Littoral Zone*

The littoral zone encompasses the area of a lake between the open water pelagial zone and the uplands of the drainage basin (Wetzel 1975). It generally extends from the depth of rooted plant growth, usually 15 to 25 feet deep, shoreward to the beach area affected by waves at the high water elevation. Submersed plants generally do not grow below a depth of 30 feet due to light and pressure limitations. Some lakes have very small littoral zones and some lakes are comprised entirely of littoral zone. Lakes St. Clair and Erie have relatively large littoral zones compared to the other Great Lakes. Houghton Lake, the largest inland lake in Michigan, is entirely littoral zone. In most lakes, the littoral complex of macrophytes and associated microflora is foremost in regulation of eutrophication rates and in the functional dynamics of the system as a whole.

The littoral zone of a lake can be broken down into a number of smaller zones. Typically, the lower littoral zone contains predominantly submersed macrophytes, the middle littoral zone contains floating-leaved rooted macrophytes, the upper littoral zone is dominated by emergent vegetation, and the eulittoral-supralittoral zones are areas influenced by waves. As discussed earlier, other terms used to describe these areas of a lake include swamp, marsh, deepwater or submerged wetland, fen, bog, and wet meadow. Hydrology, particularly water depth and duration, determine the dominant type of vegetation

Submersed macrophytes and aqueous portions of emergent and floating macrophytes provide an enormous surface area that is colonized by microflora (algae and bacteria). In addition, all other surfaces within the littoral zone are colonized by microflora that are more or less attached. An extremely diverse spectrum of microhabitats occurs in the littoral zone among substrates of sand, rock, organic sediments, and macrophytes. The massive surface area available for colonization, especially among submersed macrophytes, can result in very high contributions of attached littoral algae to the total primary productivity of many freshwater systems. When this productivity is coupled with the very high rates prevalent among the emergent macrophytes, the littoral primary productivity can form a major input of organic matter to lake systems. The littoral zone provides diverse habitats for aquatic organisms, and its components are highly important in the overall production and regulation of the lake ecosystem (Wetzel 1975).

Typical indigenous plant species found in Michigan lakes are classified within the following architectural groups:

- Low-growing: muskgrass *Chara* (a macroalgae), southern naiad, Robinson pondweed, and bladderwort.
- Mid-water: large-leaf pondweed, water star-grass, flat-stemmed pondweed, sago pondweed, eel grass (wild celery), smartweed, and waterweed.
- Full water column: American pondweed, Richardson's pondweed, variable pondweed, white-stemmed pondweed, Illinois pondweed, coontail, and water-milfoil.
- Floating-leaved: water-lilies, floating-leaf pondweed, and watershield.
- Emergent: arrowhead, bur-reeds, swamp loosestrife, arrow arum, pickerelweed, cat-tail, wild-rice, reed canary grass, spike rush, bulrush, and sedge.

Aquatic macrophytes are an essential habitat component of lake ecosystems and contribute many benefits to aquatic communities. Natural plant species composition and distribution within lakes are influenced by lake size and depth, wave energy, water currents, ice-scour, bottom slope, sediment composition, and water chemistry and clarity. The heterogeneity of sediment composition is influenced by the physical characteristics of a lake. Sediment composition combined with depth strongly influences both species composition and biomass of the plant community (Duarte and Kalff 1988; Johnson and Ostrofsky 2004). Canopy-erect species (e.g., coontail, water-milfoil, pondweeds) dominate where nutrients are abundant, and bottom-dwelling species (e.g., eel grass, water marigold, muskgrass, naiads, water star-grass) dominate where sediments are infertile. Areas of lake where physical conditions (wave, ice-scour, water currents) are more severe have a tendency to be poorer in nutrients.

Generally, macrophyte production tends to be lower in oligotrophic lakes and higher in mesotrophic-eutrophic lakes. However, naturally oligotrophic lakes often have dense stands of macrophytes as part of the overall plant community.

Macrophytes are important in determining type, structure, and production of fish communities, and they influence fish behavior (Hall and Werner 1977; Werner and Hall 1977; Miranda and Hubbard 1994; Randall et al. 1996). Aquatic plants play a key role in different life stages of many fish species, including serving as substrates for eggs and providing habitat for some species that require plants for their existence (Scott and Crossman 1973; Trautman 1981; Becker 1983). Janacek (1988) provided a literature review of 119 papers in relation to fish interactions with aquatic macrophytes. He found that 44 species of fish were found to spawn in, on, or near macrophytes, and 84 species of fish utilized macrophytes to satisfy some habitat need. Most of these species are found in Michigan and include the principal game fish. Fish that inhabit the littoral zone are known to segregate predominantly by habitat (Werner et al. 1977; Schneider 1981; Keast 1984; Weaver et al. 1997). Submerged macrophytes create areas favorable to invertebrates that are a principal source of food for many fish (Keast 1984; Wiley et al. 1984; Engle 1985). Macrophytes offer spatial diversity for fish providing both open and complex areas for foraging and predator avoidance (Keast 1984; Kilgore et al. 1989; Smith 1993).

Fish biomass is directly related to aquatic macrophytes in inland lakes (Schneider 1975, 1978, 1981; Durocher et al. 1984; Wiley et al. 1984; Kilgore et al. 1989; Bettoli et al. 1993; Hinch and Collins 1993). Schneider (1975, 1978) determined that submersed macrophyte abundance was one of four principal components regulating the biomass of fish in Michigan lakes. Schneider (1981) also determined that the better fishing lakes in Michigan contained moderate densities of aquatic macrophytes. Fishing quality was related to size structure and growth rates of game fish. Durocher et al. (1984) found that any reduction of aquatic macrophytes below 20% of total lake surface area resulted in a reduction in the bass fishery. He had data only to a maximum of 20% of lake surface area, so he was not able to evaluate higher levels of plant coverage. Wiley et al. (1984) estimated 36% macrophyte coverage was optimal for bass populations in Illinois ponds. Theiling (1990) related growth rates of bluegill in Michigan lakes to percent macrophyte coverage of total lake surface area. Growth index values were always positive below 33% macrophyte coverage. Bluegill growth index values at higher levels of macrophyte coverage ranged from negative to positive. This information indicates that above average bluegill growth is common in lakes with macrophyte coverage up to 33% of total lake surface area. Lakes with higher levels of macrophyte coverage can have above average bluegill growth, but usually have average or below average growth.

Macrophytes are equally important for determining a lake's value to wetland wildlife. The distribution and abundance of plants in shallow zones of lakes can directly influence use by species of dabbling ducks and wading birds (Kaminski and Prince 1981; Monfils 1996; Soulliere and Monfils 1996). Areas having a "mosaic" or mixture of aquatic plants and open water often have the highest species diversity and overall use by these bird groups. Some species of shorebirds also prefer shallow water areas with macrophytes, whereas others depend on the mudflats commonly found in the upper littoral zone (Helmers 1992). Submerged plant leaves and roots (tubers) are used as food by several species of wildlife. In addition these plants act as substrate for aquatic invertebrates like insects and snails, important food sources for many waterbirds. Emergent plants provide both food and protective cover, plus nest-building material for birds and aquatic mammals (Baker 1983). A variety of amphibians and reptile species depend on the littoral zone, and they represent additional critical elements of these complex lake communities.

### *Pelagial and Profundal Zones*

The pelagial and profundal areas of a lake are important in processing dissolved and particulate organic compounds critical to energy flow in the system, the annual cycling of nutrients, producing phytoplankton and zooplankton, and as feeding and refuge areas for small invertebrates, fish, and birds. Diving ducks are especially obvious on open water lakes where they feed on mollusks, crustaceans, and submerged aquatic plant leaves and tubers. Loons, grebes, and terns commonly fish the pelagial zone of lakes. Some lakes have no true pelagial zone and others have very large open water areas. Waters of the epilimnion are usually well mixed and oxygenated during summer months. The hypolimion may be depleted of oxygen during summer months, and sometimes during winter months.

Lakes Superior, Michigan, Huron, and some inland lakes have very large, deep pelagial zones. The hypolimnion contains cold, well-oxygenated water throughout the summer months. These types of lakes are typically oligotrophic and low in nutrients and productivity, and the profundal zone remains aerobic with high rates of organic matter decomposition. Coldwater and coolwater aquatic communities are supported in these lakes because the cold waters of the hypolimnion remain oxygenated.

Most large inland lakes have moderately large pelagial zones and hypolimnions relative to the littoral zone. The hypolimnions of many of these often become devoid of oxygen during summer. The hypolimnion and profundal zones become anaerobic and organic matter decomposition rates decrease. Typically these lakes have warmwater aquatic communities.

### *Bogs*

Bogs are unique because their nutrient-poor, acidic nature promotes high organic matter accumulation (refer to the Trophic state section). The rapid accumulation of organic matter can turn an open water lake into a forested wetland at a greater rate than a typical lake.

Relatively few aquatic animals have adapted to the extreme acidity and low salinity of bog waters. Species diversity is very low and entire groups of animals are lacking or poorly represented, including mollusks and fish.

Bogs support a specific group of carnivorous plants such as pitcher plants, sundews, and bladderworts that eat insects and are able to retain water from precipitation. Common shrubs include leatherleaf, bog laurel, bog rosemary, and Labrador tea. Blueberries and cranberries are also common. American goldfinch, song sparrow, American woodcock, alder and willow flycatchers, and golden-winged and chestnut-sided warblers are birds found using bogs. Ruffed grouse eat the catkins of bog birches, which often grow around the edges of bogs and fens, and migrating ducks use the open pools of bogs for resting. Because bogs support insects, shrews, mice, frogs, toads, and other species in the food chain, they also attract mink, raccoons, herons and other predators. A unique species occurring in bogs and adjacent meadows is the southern bog lemming.

### *Beaver Impoundments*

A high proportion of the small (<5 acres) inland lakes found in northern Michigan are created by beaver. Beaver ponds are usually temporary, lasting from a couple years to a couple decades, until food depletion (particularly poplar and willow trees) encourages abandonment by a beaver colony (Baker 1983). Following beaver emigration, dams deteriorate and associated impoundments drain, which results in stands of aquatic macrophytes being replaced by herbaceous plants adapted to dryer soils. Trees eventually return to most “beaver basins,” and the cycle begins again, increasing temporal diversity to local plant and wildlife communities.

The use of beaver impoundments by wildlife is greater than for other small natural lakes in northern Michigan. Beaver droppings and the materials pulled from uplands provide fertilizing agents and structure to wetlands that can otherwise be generally sterile and unproductive, especially in the Upper Peninsula. Various characteristics of beaver impoundments, such as excavated channels, shallow and deepwater zones, aquatic macrophytes, and woody debris (lodges, food caches, dams and feeding sites) result in a diversity of micro-habitat for many wildlife and some fish species. A recent study completed in northern Minnesota revealed that productive and diverse fish assemblages (non-trout species) in headwater streams required the entire mosaic of successional habitats associated with beaver activity, including those due to the creation and abandonment of beaver ponds (Schlosser and Kallemeyn 2000). Thus, the diversity of site-level and landscape-level features associated with beaver lakes can result in wildlife and fish diversity and abundance that surpasses that found on other small northern lake basins.

### *Wetland Habitats*

At the time of European settlement, the area that is now the conterminous United States contained an estimated 221 million acres of wetlands. In 1997, there were an estimated 105.5 million acres left (Dahl 2000). The rate of wetland loss was estimated for several periods as follows: mid 1950s to the mid 1970s – 485,000 acres/yr; mid 1970s to the mid 1980s – 290,000 acres/yr; and 1986 through 1997 – 58,500 acres/yr. Between 1986 and 1997, the net loss of wetlands was 644,000 acres. Ninety-eight percent (633,500 acres) of all losses were to freshwater wetlands. In 1997, there were an estimated 100.2 million acres of freshwater wetlands remaining, including 50.7 million acres of forested wetlands, 25.2 million acres of freshwater emergent wetlands, 18.4 million acres of freshwater shrub wetlands, and 5.5 million acres of freshwater ponds. Since the 1950s, freshwater emergent wetlands have declined by the greatest percentage of all wetland types with nearly 24% lost. Freshwater forested wetlands sustained the greatest overall loss in area, declining by 10.4 million acres. National wetland losses were attributed to urban development (30%), agriculture (26%), silviculture (23%) and rural development (21%). Dahl (2000) concluded that substantial progress had been made in reducing the rate of wetland loss, but the goal of no net loss of wetlands had not been achieved.

Michigan's landscape has been modified extensively from conditions present prior to European settlement. Logging, farming, residential, urban, industrial, and recreational development have removed wetlands through draining and filling. Wetland losses in Michigan, compared to conditions at the time of European settlement, have been estimated as high as 70% (Herman et al. 2001). Wetlands along the shorelines of lakes have been severely depleted in many instances as a result of human development. It should be emphasized that estimated wetland losses only indicate losses of aquatic vegetation in the portion of a lake's littoral zone containing emergent plants. Losses of aquatic vegetation from dredging, filling, and removal programs in the remaining portion of the littoral zone in Michigan lakes have not been determined.

The Michigan Natural Features Inventory has described a number of natural communities in Michigan using a wetland classification system. They have described 30 specific palustrine communities as of March, 2003 (www.michigan.gov/dnr). Many of these have unique plant or animal communities, often containing species threatened or endangered.

Inland swamps and marshes occur within the littoral zone of lakes, along stream margins, and in isolated locations with saturated soils. Michigan swamps are often dominated by conifer trees (white cedar, black spruce, balsam fir, white pine, and hemlock) in the north and deciduous trees (silver and red maple, swamp white oak, tupelo, black ash, and basswood) in the south, but with mixed swamps in both regions. Common marsh plants include narrow- and broad-leaved cat-tails, sedges, species of arrowhead, bulrush, water-lily, eel grass (water celery), rushes, and pondweeds. Reed canary grass, woolgrass, a variety of sedges, big bluestem, prairie cordgrass and blue-joint grass are examples of wet meadow plants that can withstand occasional, temporary flooding. As soils become more saturated, red-top grass, goldenrod, Joe-pie-weed, marsh aster and other marsh plants begin to dominate wet meadows. Sedges like bottlebrush sedge and lake sedge dominate where the soils are saturated most of the year. Southern Michigan marsh often grades into shrub swamp dominated by dogwood and willow.

Swamps and marshes provide habitat for wildlife, including mammals such as muskrat, raccoon, mink, cottontail rabbit, and white-tailed deer. Wading birds (herons and bitterns), shorebirds, waterfowl, terns and many species of songbirds seek nest sites and food in marshes and swamps. Shorebirds commonly found using marsh mudflats include greater and lesser yellowlegs, killdeer, common snipe, and solitary sandpiper. Less common bird species that live in marshes include the black tern, American bittern, least bittern, and king rail. Dense cattail stands provide quality winter habitat for ring-necked pheasants. They also supply food and cover to leopard frogs, chorus frogs, snapping turtles, red-eared slider turtles, northern water snakes, and ribbon snakes.

Swamps and marshes have significant fisheries values. Typical fish that use swamps and marshes for spawning or nurseries include northern pike, yellow perch, bluegill, largemouth bass, and a variety of minnow species.

Various types of wildlife rely on springs and seeps when rivers, creeks, ponds and other water sources are absent. Because they do not readily freeze during winter months, they offer a dependable source of flowing water year around. In addition, the ground water that percolates at lower elevations often creates a snow-free area in winter and provides wildlife with access to green vegetation. In spring and summer, reptiles and amphibians, including several kinds of salamanders favor the constantly moving shallow water of springs and seeps.

Coastal wetlands are found along the Great Lakes, their connecting waters (e.g., St. Mary's River, St. Clair River), and in lakes connected by streams (drowned river mouth lakes) and tributary estuaries influenced by Great Lakes water levels. Great Lakes wetlands are considered to be the some of the most productive natural systems in the temperate zone of North America. Some of the special communities found within Great Lakes wetlands are very rare and considered globally imperiled.

Typical plant species associated with Great Lakes wetlands include: button bush, silky dogwood *Cornus amomum*, red-osier dogwood *Cornus racemosa*, and willow in the shrub swamps; hardstem bulrush, three-square, softstem bulrush, *Phragmites*, giant bur-reed, common arrowhead, water plantain, pickerel weed, and cattail in the shallow emergent plant zone; and Eurasian water-milfoil, pondweed, wild celery (eel grass), naiad, and common waterweed in the submerged zone. Muskgrass *Chara* (a species of macro-algae) is also commonly found growing on the bottom of the submerged zone.

Great Lakes wetlands provide habitat for a wide diversity of animal species. Thirty-nine species of amphibians and reptiles and 15 species of mammals occur in the St. Clair system (Hendendorf et al. 1986). Typical waterfowl species observed on Michigan wetlands include: 3 species of swan, 2 species of geese, and 21 species of ducks. Birds other than waterfowl that may be found in the Great Lakes system include: grebes, rails, herons, plovers, sandpipers, gulls, terns, hawks, bald eagle, osprey, American kestrel, short-eared owl, belted kingfisher, and an extended list of perching birds (Edsall 1988). More than 48 species of fish and several species of invertebrates are known or presumed to use the coastal wetlands of the Great Lakes.

The lake-plain prairie system typically occupies the position between the shallow emergent marsh zone of the Great Lakes marsh community and the adjacent uplands. It also can occur inland on the glacial lake-plain landform in shallow depressions. Lake-plain prairie and lake-plain oak openings are considered globally imperiled by The Nature Conservancy. The majority of wet prairie along or near the shorelines was drained in the mid-late 1800s and converted to agriculture or developed. At present, the amount of remaining lake plain prairie is approximately 1,000 acres or 0.7% of the original prairie present at the time of European settlement (Comer et al. 1995). The St. Clair area contains 25% of the lake-plain prairie in Michigan. Statewide, 53 plant species, 6 insect species, 2 bird species, and 1 species of snake associated with lake-plain prairies are state listed as endangered, threatened, or special concern.

## Stresses and Threats to Natural Resources of Michigan Lakes

Human development for commercial, agricultural, residential, and recreational purposes occurs throughout our landscape, along shorelines, and within lakes and wetlands. Alterations of natural conditions can be minor to very extensive within any specific watershed. Changes from human development have been occurring in Michigan for over 150 years. Accumulation of many small changes over this time period has led to completely altered landscapes, and people often do not have a clear understanding of a lake or its watershed's natural condition. Watersheds are complex and function as ecological units, so changes in one part of the system often have widespread or cascading effects on the entire system (Schindler and Scheuerell 2002).

Alterations that almost always have whole-lake affects include changes in the uplands of the watershed; particularly artificial drainage systems, removal of wetlands, fertilization practices, use of pesticides and other chemicals; construction and operation of lake-level control structures; introduction of non-indigenous species; and shoreline development by people. Drainage, removal of wetlands, fertilization, and chemical use affects the quantity and quality of water lakes receive. Drainage increases the flow of water over the surface of the land, resulting in increased erosion of sediment, and increased nutrient and chemical runoff. Historically, wetlands naturally provided filtering of nutrients and sediment from runoff, but these buffers have largely been removed from our landscape, especially in southern Michigan. Fertilization for agriculture has significantly increased nutrient content in our soils, surface waters and ground waters. Residential, industrial and agricultural use of pesticides increases pollutant runoff into our lakes. Increased erosion of sediment causes accelerated filling of our lakes. Increased nutrients cause eutrophication. More eutrophic lakes generally have higher levels of algae in the water column, resulting in decreased clarity and light penetration and changes in algal species. Reduced light penetration results in lower aquatic macrophyte growth. Increased deposition of organic matter results in oxygen depletion in the hypolimnion, and increased nutrient recycling within the lake. Nutrients in the bottom sediments eventually build up and contribute to increased in-lake nutrient recycling or increased growth of macrophytes. All of these factors affect habitat requirements of aquatic organisms. Shoreline development and direct removal of aquatic macrophytes reduces habitat for animals living within the lake and along its borders. Habitat degradation disrupts the ecological integrity of the system, affecting species composition, distribution, and abundance of animal resources.

### *Cumulative Effects of Small Modifications to Habitat*

Resource professionals have known for many years that within lake watersheds, small changes to habitat accumulate and have detrimental affects on natural resources at various scales. Burns (1991) summarized the American Fisheries Societies concerns with cumulative effects of small modifications to habitat, indicating that resulting changes not only have local effects, but also watershed, regional, oceanic, and global scale effects. They should therefore be evaluated and viewed from those perspectives. Cumulative effects result from complex relationships among spatial, temporal, and compositional changes made to the habitat of any species or biological community. The American Fisheries Society considered this issue important enough to establish a resource policy on cumulative effects of small modifications to habitat (Rasmussen 1997).

Within Michigan, both the Great Lakes and the majority of inland lakes have experienced substantial cumulative alteration of natural habitat. Fisheries resources of the Great Lakes have been severely altered from original conditions prior to European settlement, including changes in dominant fish species, extinction of species, and declines in overall productivity (Smith 1970). These changes resulted from the accumulation of numerous human-induced alterations including, introduction of exotic species by barrier removal, overfishing, dam construction across tributaries, deforestation of the landscape, artificial drainage, wetland losses, nutrient pollution, and chemical pollution. These were coupled with lack of inter-jurisdictional resource management, inappropriate laws, and political neglect regarding natural resources. Some of these issues, like cooperative resource management and overfishing are less important today, but many of these problems continue.

A number of recent studies document the cumulative effects of small modifications to habitat on biological communities resulting from human lakeshore development in north temperate lakes. Deadwood (coarse woody debris) is a habitat component of north temperate lakes that is produced immediately adjacent to lake shorelines or streams flowing into lakes. The ecological function of deadwood is not as well known in lakes as in streams, but it does provide an important substrate for plants and animals in the littoral zone of lakes (Bowen et al. 1995; France 1997), provides spawning habitat for fish, serves as cover and a predation refuge for fish (Hanson and Margenau 1992; Rust et al. 2002), may provide a significant amount of dissolved organic carbon, and protects shorelines from wind and ice erosion. Guyette and Cole (1999), found that eastern white pine logs were very persistent in Swan Lake, Ontario, dating from calendar years 982–1893. Accelerated inputs of deadwood occurred during the late nineteenth century logging period, but little had fallen into the lake during the past 100 years. Most (79%) of the eastern white pine in the lake had drifted from the original position to other areas of the lake consistent with prevailing winds. Eastern white pine may float for many centuries and be moved by wind and ice formations.

Christensen et al. (1996b) found that deadwood was significantly greater in undeveloped lakes than in developed lakes in northern Wisconsin and Michigan. Deadwood found within the lake was positively correlated with levels of riparian tree density and negatively correlated with cabin density. The strength of the statistical relationship between riparian tree density and deadwood in the lake was dependant on the spatial scale at which it was measured. Lakewide analyses produced stronger statistical correlations than analyses at the smaller spatial scale of individual sampling plots. Dwelling densities ranged from 0 to 40/mi of shoreline. Overall, there was significantly more deadwood (logs 2 inches and greater in diameter) in undeveloped lakes (mean = 893/mi of shoreline) than in developed lakes (mean forested = 610/mi of shoreline, cabin occupied = 92/mi of shoreline). Regression analyses indicated densities of deadwood logs in undeveloped lakes ranged from 470 to 1,545/mi of shoreline. Predicted dwelling densities corresponding to these log densities were 0.3–7.5/mi of shoreline. Densities of shoreline trees (including dead trees) within 33 ft of the shoreline (normal drop distance to water) at undeveloped lakes ranged from 363 to 1,017/acre. Based on these observations, Christiansen et al. (1996) estimated that losses of deadwood resulting from development of the shoreline will affect the littoral communities of lakes for about 2 centuries.

Radomski and Geoman (2001) found that developed shorelines had substantially less emergent and floating-leaf vegetation than undeveloped shorelines in Minnesota lakes. Developed shorelines averaged 66% less vegetative cover relative to undeveloped shorelines. Overall, loss of vegetation in centrarchid-walleye lakes was estimated at 20–28% based on present housing densities, and projected losses for 2010 may be as high as 45% based on lakeshore housing growth estimates. Significant aquatic vegetation losses were visible at dwelling densities of 9.6/mi. Both biomass and mean size of northern pike, bluegill, and pumpkinseed were correlated with emergent and floating-leaf vegetation. Biomass and mean size of fish were positively correlated with increasing vegetation coverage, with the exception of mean size for northern pike.

Rust et al. (2002) evaluated lake characteristics influencing spawning success of muskellunge in northern Wisconsin lakes. The most important characteristics found were human development of the shoreline; amount of deadwood per mile of shoreline and percentage covering spawning habitat; natural seasonal water level fluctuations; and amount of soft, organic, nitrogen-rich sediment. Lakes with self-sustaining muskellunge populations were mostly surrounded by forest, whereas lakes that required stocking had less shoreline in a natural state and more human development.

Bryan and Scarnecchia (1992) evaluated species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of Iowa's 6,000-acre Spirit Lake. Young-of-the-year fish communities in naturally vegetated sites were compared with those inhabiting nearby sites where lakeshore development (i.e., homes, boat docks, and beaches) reduced nearshore macrophyte species richness and abundance. Plant species found in natural sites were similar to those found in Michigan lakes (dominated by *Potamogeton* spp.). Emergent vegetation (e.g., *Schoenoplectus acutus* and *Typha* spp.) was absent from developed sites. Species richness and total fish abundance were consistently greater in natural sites compared to developed sites in both nearshore (0–1m) and intermediate (1–2m) depth zones, but differed little between natural and developed sites in the offshore (2–3m) zone. Nearly 50% of the species sampled, including yellow perch and bluegill, inhabited limnetic areas as larvae before migrating inshore as juveniles. Eighteen of the twenty species collected as juveniles were greater in abundance in natural sites compared to developed sites. Smallmouth bass and darters were found in equal or greater abundance in developed sites. Longnose gar, northern pike, yellow bullhead, banded killifish, green sunfish, black crappie, yellow perch, largemouth bass, bluegill, spottail shiner, bluntnose minnow, and black bullhead were scarce or absent from developed sites.

Schindler et al. (2000) evaluated patterns of fish growth along a residential development gradient in north temperate lakes. Bluegill and largemouth bass growth was studied in 14 lakes located in northern Wisconsin and northern Michigan. Size-specific growth rates for both species were negatively correlated with the degree of lakeshore development, although this trend was not statistically significant for largemouth bass. On average, annual growth rates for bluegill were 2.6 times lower in heavily developed lakes than in undeveloped lakes. Bluegill populations were approximately 2.3 times less productive in highly developed lakes than in undeveloped lakes. They concluded that extensive residential development of lakeshores may reduce the fish production capacity of aquatic ecosystems. Study lakes and dwelling densities (0–40/mi) were the same as Christensen et al. (1996b).

Jennings et al. (1999) evaluated the basin-wide and local effects of cumulative habitat modifications in Wisconsin lakes. By evaluating an index of lake trophic status (cumulative phosphorus increases over time), they were able to show a shift in the fish species assemblage with increasing phosphorus levels. Intolerant species became less abundant and tolerant species more abundant on a lake-wide level. Fish species richness comparisons were made between natural shorelines, vertical seawalls, and rip-rap. Species richness was greatest at sites with rip-rap followed by natural shorelines. However, this information has a different ecological meaning when viewed from a larger spatial scale. Although rip-rap increased structural complexity at the scale of the individual site, when viewed at the scale of the whole lake, conversion of the entire shoreline to this one habitat type would not increase habitat diversity, but cause a reduction. Thus, conversion of unaltered shorelines to rip-rap should not be viewed as an enhancement. But rip-rap provides better fisheries habitat than retaining walls when erosion control is a necessity. Both spatial and temporal scales were important in evaluating the effects of cumulative habitat modifications in these Wisconsin lakes.

Jennings et al. (1999) discussed the implications of habitat alteration in relation to regulatory programs and public perception. Most alterations of littoral zone habitat in central North America are incremental and cumulative, occurring primarily at the spatial scale of individual recreational and residential properties. Many heavily affected lakes in this region did not undergo single large, drastic alterations but were subject to numerous small modifications to structural components of habitat and gradual shifts in land use. This study demonstrated that local habitat modifications lead to small changes in local species richness, but more importantly, assemblage structure responds at larger spatial scales, when many diverse incremental changes have occurred within a basin over time. Regulatory programs designed to protect ecosystem function by conserving small fragments have merit, even if local responses to small changes are not immediately measurable. Biologically, the objective is to maintain ecosystem function at the landscape scale, but the regulatory tools apply to small shoreline fragments that are often incorrectly perceived to be ecologically insignificant.

Woodford and Meyer (2003) evaluated the impact of lakeshore development on green frog abundance in 24 northern Wisconsin lakes. Green frogs are a shoreline-dependent species that inhabit nearly all types of permanent water in the region studied, establish and defend distinct territories, and tend to remain along the periphery of lakes and ponds throughout the summer breeding season. Adult green frog populations were significantly lower in lakes with developed shorelines (average dwelling densities = 20.9/mi) than lakes with little or no development (average dwelling density = 2.9/mi). Suitable habitat, rather than development density, was the primary factor affecting adult frog abundance. Greater development densities significantly decrease breeding habitat quality, resulting in lower adult frog abundance. Adult green frog densities ranged from 1.6 to 106.2/mi of lake perimeter. Wisconsin has regulations that limit the maximum development density surrounding lakes to 53.1

homes or cottages per mile of shoreline. Woodford and Meyer (2003) estimate if a Wisconsin lake was developed to its regulatory potential, less than 50% of suitable shoreline habitat would remain and the local green frog population would disappear. Their findings suggest current regulations and enforcement are not protecting the shoreline habitat that is crucial to sensitive amphibian populations in Wisconsin.

Lindsay et al. (2002) studied the influence of lakeshore development on breeding bird communities in a mixed northern forest. Thirty-four paired lakes were studied for breeding birds in lacustrine habitats of northern Wisconsin. Significant differences were not found between developed and undeveloped lakes in bird abundance, richness, or species diversity. Significant declines in the prevalence of insectivorous and ground nesting birds were documented on developed lakes, contrasting with increased prevalence of seed-eating birds and deciduous-tree nesting birds. Changes in diet guild diversity appeared to occur near a development threshold of 4.8–6.5 dwellings per mile of shoreline.

All of the recent studies evaluating effects of human development on lakeshores and lake watersheds indicate long-term cumulative ecological degradation of natural lake communities. It is essential that biologists define the appropriate spatial, temporal, and component scales to evaluate the effects of cumulative habitat modifications within our lake ecosystems. Cumulative habitat effects must be considered in all lake management activities.

### *Artificial Drainage*

Artificial drainage includes establishment of legal drains, road drains, agricultural drains and field runoff, urban stormwater drains and runoff, and residential drains. Artificial drainage changes the pattern of water flow from groundwater seepage to surface water runoff. Increased surface water runoff increases nutrient, sediment, and chemical pollutant discharge into lakes. This degrades water quality conditions in lakes and generally affects the entire lake, often dramatically.

Drainage often is established in areas with high groundwater tables, so it is often directed at removing wetlands. This removes the natural filtering capacity of wetlands resulting in even more pollutants reaching lakes. Historical losses of wetlands in Michigan have been estimated as high as 70%. Wetland losses continue, although in recent years the rate of loss has diminished.

### *Water Temperature and Dissolved Oxygen*

Water temperature and dissolved oxygen are critical habitat components for aquatic organisms. Generally, direct effects from human activities on these components are relatively limited. Some large industrial discharges can have significant effects. More often, human activities indirectly affect water temperature and dissolved oxygen. All activities affecting trophic status, especially nutrient (fertilizers, septic tanks) and organic carbon contributions, can have effects on dissolved oxygen levels. Vegetation control programs can affect both water temperature and dissolved oxygen levels (refer to *Vegetation control and Swimmer's Itch control*)**.**

### *Nutrient, Pesticide, and Chemical Pollutants*

Nutrient and pesticide use occurs in both agricultural areas for crops and residential areas for lawns. Chemical pollutants come from industrial discharges, urban street runoff, and improper disposal from residential areas. Nutrient increases result in eutrophication that usually affects the entire lake. Moderate to highly eutrophic lakes generally have high algal abundance in the water column, resulting in decreased clarity, light penetration, and changes in algal species. Reduced light penetration results in lower aquatic macrophyte growth. Increased deposition of organic matter results in oxygen depletion in the hypolimnion, and increased nutrient recycling within the lake. Nutrients in the bottom sediments eventually build up and contribute to increased in-lake nutrient recycling. All of these factors affect the basic habitat of aquatic organisms. Pesticide and other chemicals can directly affect the health of biological organisms using the lake, and also result in human health effects.

Nutrient runoff from upland activities such as agriculture or lawn maintenance can also negatively affect Great Lakes coastal wetlands. High levels of nitrate and phosphorus favor exotic or invasive plant species, such as purple loosestrife and giant reed *Phragmites*, over native species and at high levels can actually prevent the establishment and growth of plants. Few comprehensive water quality investigations have been conducted, and measurements in the coastal wetlands are rare.

### *Dams and Lake-Level Control*

Lake-level control structures are used to establish and maintain abnormally high lake levels (usually during open water periods), and low (nearer natural) lake levels during periods of ice cover. The stable, high water levels are favored by lakeshore residents for boating, and low levels prevent ice damage to docks and lawns. Legal lake levels are established under P.A. 451, Natural Resources and Environmental Protection Act, Part 307, Inland Lake Levels. Augmentation wells also can be used to maintain artificially high water levels in lakes.

Lake-level control with structures or augmentation wells can have significant effects on entire lake ecosystems, especially in relation to shoreline areas of the lake, fish spawning, fish movements, community diversity, and plant and animal production (Wilcox and Meeker 1992). Dams prevent normal movements of fish in and out of the lake for seasonal habitat needs. They alter natural water fluctuations necessary for maintaining diverse and productive wetland plant communities, and nesting and rearing habitat for fish, mammals and water birds. They also increase shoreline erosion by maintaining high water levels. This generally leads to the construction of seawalls to prevent erosion. Seawalls prevent normal shoreline movements of amphibians and mammals, reduce natural shoreline vegetation, reduce emergent vegetation, and increase erosion of other shoreline areas because wave energy is not dissipated properly on seawalls and is transferred to other shoreline areas.

Extended artificial high water levels can severely alter or eliminate specific plant communities by creating unfavorable habitat conditions. The periodic drying of shoreline wetlands is important to allow the soils to aerate, to accelerate decomposition of detritus, and to facilitate nutrient exchange. Wetlands are typically more productive (plant vigor, aquatic invertebrate abundance, and wildlife diversity) following periods of dryness. Seasonal, annual, and multiple-year drought periods have been part of the natural cycle and ecosystem processes of Michigan lakes for thousands of years. Unnatural water manipulations affect ecosystem integrity of both the Great Lakes and inland lakes.

Recreational and hydroelectric dams prevent fish movements into lakes and the natural downstream movement of deadwood. This is of particular concern for the Great Lakes where deadwood inputs to tributary streams have been significantly reduced since the early to late 1800s. Great Lakes fish movements, spawning, and recruitment are also impaired by dams.

### *Non-indigenous Species*

There are presently 209 known, non-indigenous plants and animals that have been introduced into the Great Lakes basin between 1800 and 1999, of which 77% (162) are aquatic species (Harrison 2003). Routes of entry into the Great Lakes basin include ballast water from ships, canals, roadways and railways, intentional and unintentional releases, and many unknown sources. The introduction or invasion of exotic species can result in significant changes that usually affect the entire lake. Non-indigenous species that have been present for many years in our lakes include alewife, sea lamprey, common carp, goldfish, and rainbow smelt. These species have caused significant changes in both Great lakes and inland lake aquatic communities.

Species that presently are invading many lake systems include zebra mussels *Dreissena polymorpha*, curly-leaf pondweed, Eurasian water-milfoil, purple loosestrife, *Phragmites*, gobies, ruffe, various micro-invertebrate zooplankton (*Bythotrephes cederstroemi*, *Cercopagis pengoi*, *Daphnia lumholtzi*), rusty crayfish, and many others. Of particular note, curly-leaf pondweed and Eurasian water–milfoil are plant species that have spread rapidly throughout Michigan and have moderate to extreme effects on native submersed plant communities. These plants have aggressive growth habits and sometimes will completely dominate plant communities causing losses of native plants (Boylen et al. 1999). They also can grow in very dense mats to the surface of the water and are often considered to be a nuisance to some recreational activities. When these species dominate the plant community, they provide less valuable habitat than native plants (Savino and Stein 1982; Keast 1984; Savino and Stein 1989; Smith 1993). They can also coexist in plant communities without significant effects on the ecosystem (Barko et al. 1994), especially if native plants are diverse, healthy, and undisturbed. In contrast, control programs may sustain non-indigenous species for a greater number of years than would occur without management activities (Chambers et al. 1994). This may be related to the failure of controlled plant beds to develop an herbivore community, and the ability of aggressive exotic species to expand into areas devoid of vegetation resulting from control programs.

Generally, invasive plants become established and grow more extensively in water bodies that have intensive human use and development (Nichols 1994). Heavy use of a lake increases the chance of introduction by watercraft and residential activities. Once established in a waterbody, they can expand aggressively because of their growth characteristics and lack of predators. Eurasian water-milfoil can spread easily because new plants can grow from small fragments of stems, and it can crowd out other plants because it grows in thick, dense mats. Curly-leaf pondweed grows in dense stands and forms an abundance of turions that produce new plants during the next growing season.

Purple loosestrife and giant reed have had similar effects on plant communities of swamps and marshes. Disturbances to natural vegetation from farming, building, and practices that directly remove native vegetation increase the spread of invasive plants.

Zebra mussels and non-indigenous zooplankton have caused shifts in the species composition and abundance of lower food chain biota. This has been ongoing in the Great Lakes and is beginning in inland lakes as these species expand their range. Gobies and ruffe are new species to the Great Lakes that are highly competitive and are expected to cause shifts in biological communities. Invasion by rusty crayfish has resulted in the extirpation of native crayfish in some Michigan systems.

### *Shoreline Development*

Construction of buildings, seawalls and lawns along lakeshores removes natural vegetation that mammals, birds, amphibians, reptiles, and fish require. Septic tanks and lawn fertilizers leach nutrients into the lake, having the same effects on water quality as agricultural fertilizers. Wetlands are often cleared and drained for buildings. Many Michigan lakes presently have little, if any, naturally sloped or vegetated, shoreline remaining.

### *Dredging and Filling*

Dredging and filling activities occur for many reasons and alter the natural habitats and communities in a lake. Generally, most dredging activities are conducted in the littoral zone, altering the most biologically productive area of lakes. Filling activities may be conducted in any part of the lake, often including the shoreline ecotone. Filling within the shoreline ecotone is responsible for the loss of many wetlands. Filling within the lake removes valuable, productive aquatic habitat and removes navigable waters from public use. Dredging and filling is typically conducted for marina and dock construction, boating channels, dockage, seawall construction, extension of upland properties, removal of sediment and vegetation, building construction, beach sanding, waste disposal, and reef construction.

Seawalls are constructed along the shore of lakes to prevent natural erosion of the shoreline. Seawalls eradicate the natural slope of the shoreline caused by wave action and annual water level changes in lakes. They also are constructed to provide docking of boats and to provide a manicured look to lawns and properties along the shoreline. Seawalls are constructed of metal, stone, or wood, and may extend out into the lake or inland above the ordinary high water mark. The construction of seawalls has increased significantly in recent years and many of our lakes have almost no naturally shaped shoreline areas remaining.

Seawalls are detrimental to lakes in many ways. They generally remove the natural slope of the shoreline and create barriers that prevent the free migration of mammals, reptiles, and amphibians between the water and uplands. They remove the natural energy dissipating capacity of a sloped shoreline and natural vegetation, and this, in turn, causes increased erosive energy in other parts of the lake along with additional scour and deepening of the bottom and further removal of natural vegetation.

Dike and channel construction have caused significant alteration of Great Lakes marshes, especially in the southern half of the Lower Peninsula (Albert et al. 1988). Creating dikes in coastal wetlands has been done to allow farming of the productive soils and for waterfowl management. The use of dikes and pumps has helped remove water to allow farming, or to stabilize water levels in marsh communities. However, dikes are barriers that prevent natural interchange of water between deep portions of the lake and littoral areas. This interchange includes daily (wind seiche), seasonal, and long-term water-level changes that result in exchange of water, nutrients, and energy. The disruption of regular de-watering or movement of oxygenated lake water into coastal wetlands must be critically evaluated, and some dikes have been removed from state-owned coastland (Soulliere 1995). Dikes fragment coastal wetlands, reduce vegetative diversity (Keddy and Reznichek 1984), reduce water quality and fish use, and simplify invertebrate communities (Edsall 1988). Commercial dredging to create, deepen or widen channels will directly take vegetation, remove soils necessary for plant establishment, and increase rate of water flow, making it more difficult for plants to re-establish. Additional habitat degradation may occur when dredge spoils are deposited in other parts of a lake.

Reef construction is often proposed to improve fishing and diving recreation, both on the Great Lakes and inland lakes. Proposals often incorporate the use wood and foreign materials including: stone, tires, slag and other industrial waste, automobiles, buses, and ships. The use of artificial reefs to enhance habitat and improve biological communities in oceans, lakes, and reservoirs has questionable value (Merna and Galbraith 1984; Ganon 1990; Tugend et al. 2002). The principal result that artificial reefs sometimes provide to anglers is the attraction of fish to locations where they are more susceptible to angling. This often leads to management conflicts when harvest is being reduced in other ways. Great Lakes management agencies developed the International Position Statement and Evaluation Guidelines for Artificial Reefs in the Great Lakes (Ganon 1990). This document states "artificial reefs should be constructed only when there are clear benefits to fisheries without deleterious effects on the ecosystem or undue interference with other beneficial uses of the lakes", and "under no circumstances should artificial reef development be used as a pretext for the disposal of terrestrial refuse into the aquatic environment." The addition of natural materials to lakes may be acceptable when completed in an ecologically sound manner, for example, littoral zone deadwood restoration discussed in this document.

*Aquatic Vegetation Control*

Aquatic vegetation is removed from lakes to control non-indigenous species, to clear the surface of the lake for boating, to clear areas for swimming near shore, and to create “clean,” open-water appearances to lakes. The removal of native aquatic vegetation is detrimental to lakes because vegetation forms the base of the food chain and is a principal habitat component for aquatic life. Removing native vegetation destroys microhabitats, shortens food chains, opens the lake bed to invasion by non-indigenous species, and opens the shoreline to wave erosion. Removal of native vegetation promotes the spread of aggressive, non-indigenous species.

There is sometimes a social misconception in Michigan that aquatic macrophytes are bad for a lake. This negative misconception is fostered by boating and swimming enthusiasts that consider vegetation a “nuisance” to these recreational activities. The expansion of non-indigenous aquatic plant species and their control also fuels this misunderstanding. The effects of nutrient pollution are also often misunderstood and used to promote plant removal programs in lakes.

Nutrient pollution affects aquatic plant communities. Generally, excessive nutrient pollution typical of eutrophic lakes results in algal populations that can be significantly higher than normal. Increased algal biomass reduces underwater irradiance that inhibits macrophyte growth, resulting in diminished macrophyte communities. High algal populations occur when high concentrations of dissolved nutrients are present in a lake. Rooted aquatic macrophytes derive most of their nutrients from the sediments. Generally, in oligotrophic and mesotrophic lakes, nutrient enrichment of the sediments increases macrophyte biomass. Duarte and Kalff (1988) found that macrophyte biomass averaged 2.1 times greater when nutrients were added. Eurasian water-milfoil has been shown to increase biomass by 30–40% with nutrient enrichment of the sediments (Anderson and Kalff 1986). As discussed earlier, canopy-erect macrophyte species dominate areas of a lake with high sediment nutrients, while bottom-dwelling species dominate infertile sediments. Usually, the greatest plant biomass increases are likely to occur in the shallow parts of the littoral zone, where nutrients tend to be more limited.

Plant control programs designed to kill native plants do not address the nutrient pollution issue because the nutrients are cycled back into the system. This also can foster greater growth of the two important non-indigenous species, curly-leaf pondweed and Eurasian water-milfoil, because they are both canopy-erect species favoring nutrient rich sediments. The killing of bottom dwelling species that favor nutrient poor sediments also promotes the expansion of canopy-erect species because it speeds the process of sediment nutrient enrichment. Other related issues are discussed below.

There are numerous methods used to remove or control aquatic plants. All methods have advantages and disadvantages. Appropriate non-indigenous plant control methods will vary depending on individual lake conditions such as size, depth, chemistry, and the distribution and abundance of plant species. Generally, integrated control using multiple methods will be necessary for long term management.

Mechanical methods of aquatic plant removal include bottom barriers, suction or diver’s dredge, hand removal, rotovation (bottom tilling), dredging or filling sediments, and harvesting by cutting the upper portion of plants. Bottom barriers, dredging, filling, and rotovation are non-selective methods that remove both non-indigenous and native plants. Hand removal (cutting, pulling, or raking) and mechanical harvesting can be very selective and can be used to only remove a portion of the plant. The more selective methods can be used to maintain open boat channels through native plant stands, from docks to open water, without leaving the bottom open to invasion by non-indigenous species.

Mechanical harvesting causes fragmentation of plants, and should be avoided in lakes that have low to moderate levels of Eurasian water-milfoil. Eurasian water-milfoil plants can grow from small fragments, so methods that fragment plants magnify the potential this plant will increase its distribution in a lake. Mechanical harvesting removes plants and associated nutrients from lakes, but also removes many juvenile fish.

Biological methods of plant removal or control presently include introduction of herbivorous fish or insects, and the use of plant pathogens or growth regulators, which are relatively new procedures under study. Introduction of herbivorous fish, like the grass carp or white amur, is not allowed in Michigan because of the potential for damage to native vegetation. The aquatic weevil *Euhrychiopsis lecontie* is very selective and has been effective in controlling Eurasian water-milfoil (Sheldon and Creed 1995). Herbicide use and mechanical harvesting can reduce populations of herbivorous weevils (Chambers et al. 1994; Sheldon and O'Bryan 1996), and should be avoided when weevils are present.

Chemical control of aquatic plants is presently the most widely used method in Michigan. Herbicides for aquatic plant control can be described by the following general categories:

- Contact herbicides are plant control agents that are used in direct contact with foliage and destroy only the contacted portion of the plant.
- Systemic herbicides are applied to foliage and are translocated to roots or other portions of the plant, resulting in death of the plant.
- Broad-spectrum herbicides kill most if not all plants.
- Selective herbicides only kill certain plants or plant families.
- Broadleaf herbicides generally kill dicotyledons (dicots) with broad leaves.

Contact and broad spectrum herbicides generally remove native as well as exotic species. Recent studies indicate some contact herbicides can be used selectively for non-indigenous plant control early in the growing season, before native plants have emerged.

Systemic, selective, and broadleaf herbicides are generally more selective but usually kill some native plants along with non-indigenous species. Most often, the sensitivity of all plants in a lake to herbicides is not known. A good example is 2,4-D, a widely used broadleaf, systemic herbicide primarily used for control of Eurasian water-milfoil. At concentrations normally applied in lakes, 2,4-D kills broadleaf dicotyledons and monocotyledons with broadleaf morphology, but does not harm certain narrow-leaf dicotyledons (Washington State Department of Ecology 2001). In Michigan, there are 141 species of submersed and floating-leaf plants. Of these, 57 (40%) are dicotyledons, with 2 non-indigenous species and 14 threatened, endangered, or special concern species (Appendix 1). Lower concentrations of 2,4-D are more effective because high concentrations tend to "burn" the plant rather than kill it. Although 2,4-D is generally used to control Eurasian water-milfoil, at normal concentrations it also kills native milfoils and water star-grass, and at higher concentrations bladderwort, fragrant water-lily, yellow water-lily, watershield, and coontail. It also causes declines in other native species that generally recover by the end of the growing season. It is known that 2,4-D has some toxic effects on benthic organisms; information on amphibians, reptiles, and insects is lacking.

Recent studies indicate wild-rice also is affected by 2,4-D, as well as by Diquat (REWARD), endothall (Aquatholl), and fluridone (Nelson et al. 2003). Wild rice was affected to the greatest extent by 2,4-D, with significant inhibition of tiller, seedhead, and dry weight biomass production. The other chemicals inhibited dry weight biomass of young wild rice. None of these chemicals affected mature wild-rice plants. Many applications of herbicides in Michigan are applied during the early growing season when wild-rice is in the early stages of development.

Fluridone is another systemic herbicide used to control Eurasian water-milfoil. Fluridone is generally used for control programs targeted at entire lakes because it dissipates in water and cannot be controlled in small areas. Studies in Michigan found that fluridone will kill nearly all plants in a lake when used at label recommended rates (Anonymous 1997). Even at the lowest concentrations effective for controlling Eurasian water-milfoil, other common native plants are equally susceptible to fluridone (e.g., native milfoils, coontail, naiads, and *Elodea*). Other herbicides have varying advantages and disadvantages that need to be considered prior to use in controlling non-indigenous plants.

Aquatic herbicides usually do not directly kill fish at typical application concentrations, although some are more toxic than others. More often, zooplankton and macroinvertebrates are killed (Engle 1990; Washington State Department of Ecology 2001). Water quality often is affected by the use of herbicides in lakes. Dying vegetation releases nutrients and organic matter into the water that promote algal blooms. Additional applications of chemicals, primarily copper products, are then employed to control filamentous and planktonic algal blooms. Dying vegetation can also result in low dissolved oxygen concentrations in the water that may result in fish mortalities under certain conditions. Algal blooms and low dissolved oxygen concentrations both can become more pronounced as larger areas and amounts of vegetation are killed.

Copper compounds are used for algae control. Copper is the active ingredient in these products. Copper does not degrade and remains in the sediments of a lake indefinitely. The State of Washington has banned the use of copper in salmonid waters due to toxic effects (Washington State Department of Ecology 2001). The State of Washington also greatly restricts the use of copper compounds in other water bodies due to toxic effects on plants and invertebrates. Recent studies in Michigan indicate the use of copper products for control of algae and swimmer's itch (see below) can result in significant increases in copper concentrations in the sediments, with measured increases as high as 10 times natural levels (Harrison 2003).

Lake managers sometimes assume that removal of abundant plants will result in significant improvement in the size structure of slow growing bluegill populations. However, there is little empirical evidence that bluegill population size structure will improve substantially, especially for extended periods. The lack of long-term studies relating vegetation manipulation and fish populations is discussed by Carpenter et al. (1995). Schneider (2000) found some improvement in bluegill populations with removal of vegetation. Some lakes showed bluegill populations moving from poor to satisfactory levels, while others remained unsatisfactory. Olson et al. (1998) showed short-term improvement in fish growth following a specific type of mechanical harvesting pattern of vegetation. Macrophyte densities were very high and changes lasted for 1 season because vegetation grew back rapidly. In general, modeling and field studies have found that reduction of abundant, dense plant communities can increase growth and size structure of some fish, for a short time. Other methods are available for improving the size structure bluegill populations for fishing (Schneider 1993; Schneider and Lockwood 1997). Management programs designed for manipulation of specific components of a biological community must consider overall health of the ecosystem, including community rather than individual species evaluations.

Modifying a bog to convert it to a commercial cranberry marsh will destroy the original plant community. Harvesting top layers of sphagnum for commercial market will also damage the system. Researchers have little information about the recovery rate of harvested bogs but assume recovery is probably very slow or may never occur depending on the site and other land use that may be influencing the site. For example, increased nutrient supply from adjacent agricultural land may cause the edge of the bog mat to decompose at a faster than normal rate, increasing the size of the moat and potentially destroying the bog.

*Swimmer's Itch Control*

Swimmers itch (cercarial dermatitis) is caused by a larval stage of a flatworm that inadvertently burrows into the human skin. The flatworm cannot develop into the adult form, but can cause skin inflammation to allergic individuals. Control of swimmer's itch is directed at certain species of snails that serve as intermediate hosts for the flatworm. Very high concentrations of copper (>20 mg/l) are required to kill snails in waters of a lake. The high copper concentrations can kill confined fish and also other aquatic life susceptible to copper toxicity.

Blankespoor and Reimink (1991) summarized the history of swimmer's itch control in Michigan. Control programs began in the late 1930s, and have focused on the use of copper compounds. Swimmer's itch continues to be a problem in Michigan despite more than a half century of control efforts. Balankespoor et al. (2001) found that treating water birds with the drug praziquantel was effective in reducing levels of swimmer's itch, and they have used this method successfully in a number of Michigan lakes.

Species of birds that have been found to carry the flatworm include common merganser, wood duck, mallard, Canada goose, and grackle (Blankespoor and Reimink 1991). The common merganser generally is the most common flatworm carrier with high infection rates. Directing treatment programs at water birds may be more effective because typically not more than 50 will be present on a lake compared to many thousands of snails, and birds have very high infection rates compared to snails. Blankespoor and Reimink (1991) report that drug treatments of water birds appears to be more effective in controlling swimmer's itch than using copper sulfate to kill mollusks, and at the same time reduces costs and environmental risks.

*Boating and Shipping*

Boating is most detrimental to lakes when large areas of vegetation are removed to promote this activity. Vegetation control programs often target removing all vegetation within a lake that grows near the surface or in areas that inhibit the use of motors and water skiing. Substantial amounts of native vegetation removed for this purpose affect the overall ecology of the lake. The wave energy associated with high-speed boating causes beach erosion, which is exacerbated by removal of surface-growing vegetation that naturally provides wave energy reduction. Boating through vegetation also causes a great deal of fragmentation of vegetation that can promote the spread of invasive plant species. Shipping can be destructive to lakes by causing shoreline scour and vegetation removal resulting from water and ice surges as large ships pass.

## Resource Conservation Opportunities and Management Guidelines

The general ecosystem integrity of lakes is dependent on preserving natural habitat components and the processes that sustain them. These include water quality, aquatic vegetation, submerged deadwood, and naturally sloped and vegetated shorelines. Natural systems vary in productivity and diversity and maximum natural diversity should be maintained in individual lakes. It is the goal of the state to encourage the lasting conservation of biological diversity (Michigan Natural Resources and Environmental Code, P. A. 451, 1994, Part 355). Suitable natural and diverse habitat allows existence of productive and diverse animal communities.

Human development and vegetation control activities threaten habitat, productivity, and diversity of biological communities in our lakes. Habitat degradation continues to increase as human populations increase and lake properties become more developed. Some of the most prominent development activities directly affecting lakes presently include dredging for marinas and docks; filling for yard, building and seawall development; and vegetation removal programs along the shoreline and within the lake. Land use in the uplands of the watershed can significantly affect lake water quality, especially with respect to nutrients.

Most moderate and large lakes have the morphometry that provides for both the establishment of rooted vegetation in the littoral zone and a larger open water zone in the middle of the lake. This pattern has not changed since the earliest map records were made in Michigan. In other words, the vegetated areas of most lakes today are the same as in recent history. Management of public trust resources requires suitable preservation and management of this important habitat component. Recreation and reasonable use of a lake by property owners is also a management goal of the Department of Natural Resources. The objectives of lake management programs are to optimize social benefits, insure sustainable resources for the future, and maintain ecosystem integrity. Management of natural resources requires consideration of the affects of all alterations caused by development on and in a lake. It must also be recognized that some lakes are shallow and have always had vegetation growing throughout the lake. This is a natural condition of some lakes. Extensive native vegetation removal and alteration should not occur in these natural ecosystems, or a healthy system and its multiple benefits can be lost.

Non-indigenous species can threaten native vegetation and reduce overall diversity and community productivity in some situations. At present, species of concern include Eurasian water-milfoil, curly-leaf pondweed, purple loosestrife, and *Phragmites*.

### *Resource Assessments and Management Plans*

Watershed assessments and plans should be developed for all lakes. Assessments provide a complete historical and present review of the lake's physical, biological, and social characteristics. Suitable plans can then be made to insure proper management for long-term health of the ecosystem, and allow reasonable public and riparian use. Basic criteria and outlines are listed in Appendix 9.

### *Overall Development*

Alteration or development of Michigan lakes should not exceed 25% of any habitat component, water quality should be maintained within Michigan Surface Water Quality Standards, and no loss of navigable waters should occur. Development of 25% or less of the lake is recommended to provide reasonable riparian owner access and recreational use, while preserving ecological integrity, sustaining natural resources for future generations, and protecting the public trust. Development activities should be viewed from a whole lake perspective, as well as individual habitat components and individual properties. Examples of habitat components include shoreline slope and structure, vegetation (trees and shrubs) within the shoreline ecotone, emergent and submergent vegetation (distribution, composition, and architecture), submerged deadwood, lake level, bottom contours and composition, and surface water area. These objectives can be achieved on individual properties by maintaining naturally sloped shorelines, with a 35-ft vegetated buffer strip above the ordinary high water mark, and using 25% or less of the shoreline property for access and use of the lake. Boat docks and other structures should not interfere with navigation or natural movements of water or animals. A narrow boating lane can be cut through dense surface vegetation if needed, while preserving the ecological values and wave dampening features of this important habitat component.

The natural habitat features of many lakes are presently altered well beyond 25% and will require considerable restoration effort. The cumulative effects of habitat alterations must be considered in all lake management activities, including legal permitting activities for development. Cumulative habitat effects are the result of many small changes of habitat components at individual sites over a long period of time. During the past 150 years, the shorelines of many lakes have been completely denuded of natural forest and emergent vegetation, have been filled with beach sand, and have had natural slopes altered with vertical seawalls. Many of these lakes concurrently have aquatic vegetation removal programs, marinas and docks, excessive nutrient additions, and dredging and filling activities.

It is essential that managers define the appropriate spatial, temporal, and compositional scales to evaluate the effects of cumulative habitat modifications within our lake ecosystems. Considerable regulatory effort, as well as public and local community support, will likely be necessary to accomplish protection and restoration programs. An aggressive educational campaign addressing resource needs and appropriate watershed management for lakes should be initiated in Michigan. Ecological research evaluating the effects of cumulative habitat alterations on Michigan lake ecosystems is needed.

### *Water Quality*

Lake water quality should be maintained above Michigan Surface Water Quality Standards for dissolved solids, hydrogen ion concentration, taste or odor producing substances, toxic substances, nutrients, microorganisms (bacteria), dissolved oxygen, and temperature. Other inorganic and organic components should be maintained at natural levels. Water quality sampling should be conducted to evaluate these parameters. Sediment coring should be conducted to evaluate historical nutrient enrichment patterns.

Water quality degradation in most inland lakes results from development in the uplands and along the immediate shoreline of the lake. Industrial discharges are more of a concern for Great Lakes water quality than for inland lakes. Protection of water quality in lakes will require reducing artificial drainage from roadways, agriculture, urban areas, as well as from residences within the watershed and along the shoreline of the lake. Natural shoreline buffers need to be established and maintained between residential lawns and the shoreline of lakes, and riparian lawn fertilization should be discontinued or modified where it affects water quality. Central wastewater systems should be developed where septic systems are contributing nutrients to the lake.

### *Shoreline Development*

Alteration of natural shorelines should consider potential effects on habitat and biological communities, as well as the natural aesthetic aspects of lakes. Naturally sloped and vegetated shorelines should be preserved as much as possible. Shoreline vegetation should be maintained to provide natural rates of deadwood to fall into the lake, and to provide adequate habitat to maintain plant and animal communities. Natural buffer-strips should be maintained a minimum distance of 35 ft above the ordinary high water mark of a lake.

Inland lakes should be managed to contain appropriate levels of deadwood in the littoral zone. Natural levels of 2-inch and larger logs within north temperate lakes range from 470 to 1,545/mi. Tree densities (2-inch and larger) within 33 ft of the shoreline in natural lakes range from 363 to 1,017/acre. Long-term management for natural deadwood inputs to lakes should consider planning for appropriate shoreline tree densities. Existing deadwood present in lakes and shoreline deadwood should be protected from removal. Extensive logging practices and uncontrolled development of shorelines have significantly reduced deadwood inputs to Michigan lakes for over 100 years. Rehabilitation programs designed to compensate for deadwood losses should be considered. Recruitment of coarse deadwood in temperate deciduous forests was approximately estimated at 2.52 logs/ha/yr (MacMillan 1981). This is equivalent to 4 logs/mi/year within 33 ft of the shoreline.

Approximately 25% of these would be expected to fall into the lake. Tributary streams are particularly important to restoring natural deadwood inputs to the Great Lakes.

Degradation of littoral zone deadwood abundance, aquatic vegetation abundance, fish production, amphibian abundance, and fish and bird community composition have all been related to development of lake shorelines. Some of these changes were visible at dwelling densities of less than 2 per mile of shoreline. Changes in all of these resource components were visible at dwelling densities between 5 and 10 per mile of shoreline. Many Michigan lakes have dwelling densities far exceeding this level of development. Managers should recognize that resources in many Michigan lakes are in a degraded state and should incorporate development characteristics in their assessments. Shoreline protection, restoration, and rehabilitation activities should be included in all management plans and activities.

*Dredging and Filling*

Placement of permanent structures or other types of fill below the ordinary high water mark should be avoided, including beach sanding (except for natural habitat restoration). The placement of fill material in such a way that it creates a barrier to movements of water, fish, and wildlife, and even wave energy should be avoided and existing structures removed where possible. Furthermore, fill and structures that remove navigable waters or impede navigation (including shoreline access), should not be allowed because they degrade public trust resources. Seawalls should not be constructed and existing seawalls should be removed where possible. Documented needs for erosion control should use rip-rap of natural or limestone materials placed above the ordinary high water mark. Temporary docks should not interfere with fishing or navigation.

Dredging activities should be limited as much as possible. Protection of the littoral zone is especially important, as most dredging and filling activities occur in shallow water for commercial, residential, and recreational development.

*Aquatic Vegetation*

Native plants should not be removed or reduced in our lakes. Non-indigenous plants should be controlled, provided that the most selective methods that protect native plants are used. Plant communities should be protected and restored to provide lasting conservation of natural biological diversity and to maintain natural levels of production. Native species, natural diversity and architectural types, and total surface coverage and biomass of native plants should not be changed or reduced. Shallow lakes that naturally have extensive native plant cover should be maintained in their natural condition. Programs and techniques that reduce native plant or animal diversity, distribution, or abundance should not be allowed. Removal of native plants and animals promotes colonization by non-indigenous species.

Generally, inland lakes in Michigan with moderate levels of submersed plant coverage (25–35% coverage of total lake surface) have the best overall fisheries. Likewise, a mosaic of open water and 40-50% aquatic plant cover (emergent/submerged plants) is ideal for many species of wildlife. Diminished fish production is usually associated with plant coverage below these levels. Higher levels of plant coverage have high fish production, but may induce poor size structure for some fish species, especially panfish. Acceptable growth and size structure for other fish species, such as largemouth bass, and better ecological characteristics for amphibians, birds, and other aquatic organisms may compensate for the less optimal panfish population size structure. Lakes with human development along the shoreline most likely already have degraded plant communities. Biological degradation generally increases as development increases. Past and present dredging and filling activities within a waterbody need to be incorporated in evaluations of native plant communities.

Recreation needs of boaters and riparian owners must be balanced with natural resource needs to conserve biological diversity and productivity. Most natural deepwater Michigan lakes have sufficient surface acreage free of vegetation to provide adequate and balanced boater use. True “nuisance” levels of native plants that might exclude boating in areas rarely exist in deep lakes, and these are natural components of a healthy ecosystem where they occur. Natural wetland areas should be left in a natural condition. Removal of native plants promotes introduction and expansion of non-indigenous species that can reduce boater use and impair ecosystem integrity. Programs designed to remove native surface vegetation from lakes should not occur. Maintenance of boat lanes for dockage can be accomplished using mechanical harvesting methods when necessary. Shoreline erosion and plant loss should be important criteria in the regulation of commercial shipping on the Great Lakes.

Control of aggressive non-indigenous aquatic plants is generally beneficial provided the integrity of native plant communities is maintained. Species of particular concern are Eurasian water-milfoil, curly-leaf pondweed, purple loosestrife, and giant reed. Long-term planning and control for most non-indigenous species will be necessary because they are difficult to eradicate once established. Generally, non-indigenous plant control programs should be developed as part of holistic lake management plans to insure all ecological and social issues are considered.

Control programs must have appropriate quantitative evaluations of plant distribution, species composition, abundance, and historical information when available. Ancillary information, such as residential water well information, must be included to help determine appropriate control techniques. The most selective methods should be used for control programs. For example, the aquatic weevil *Euhrychiopsis lecontie* is very selective for Eurasian water-milfoil. This weevil has been effective in controlling Eurasian water-milfoil. Herbicides use and mechanical harvesting can reduce populations of herbivorous weevils, and should be avoided when weevils are present.

Both mechanical and chemical methods of non-indigenous plant control have limitations. Mechanical harvesting is more labor intensive and usually is limited to the upper portions of the plant. More frequent applications are sometimes necessary. Mechanical harvesting causes plant fragmentation, which can be a concern with Eurasian water-milfoil because new plants can grow from small fragments.

At the present time, there are no herbicides that are selective for only non-indigenous plants. The use of broad spectrum and contact herbicides is not recommended because they kill most plant life they contact. This leaves bottom areas of the lake open to invasion by aggressive non-indigenous species. Some chemicals that act as a systemic herbicide provide more selective control of Eurasian water-milfoil. These chemicals also have effects on other plants and it is necessary to have appropriate plant community information to determine when they may be used. Often, curly-leaf pondweed replaces Eurasian water-milfoil when it is removed. Curly-leaf pondweed can be controlled with mechanical harvesting, but selective chemicals are presently not available for this plant. It is important that control methods for curly-leaf pondweed control turion formation, because turions form new plants.

Control programs need to consider all alternatives. Significant infestations of non-indigenous species should have stepwise control programs that reduce plant levels over several years. Treatments restricted to one-third of the vegetated community will insure some habitat will always be available for animal communities.

The use of copper products to control algae is a serious concern due to toxic effects on biological communities and long-term accumulation in lake sediments. Control of algae should be limited as much as possible. Watershed nutrient control programs should be implemented where pollution occurs. Most chemical aquatic macrophyte control programs have associated algal control (due to nutrient releases), which needs to be considered in overall lake management activities.

*Swimmer's Itch*

Chemical control of swimmers itch needs to be carefully considered because of the longevity and toxic effects of copper used to kill host snails. Chemical control programs should insure there are reasonably significant levels of human health afflictions. Research should be conducted in Michigan to evaluate the effectiveness of control programs and their effects on lake ecology. Control programs focused on treatment of water birds with drugs should be evaluated and used when possible.

*Dams and Lake-Level Control*

Man-made dams on lakes and tributaries should be removed or managed to insure natural downstream movement of deadwood, natural upstream and downstream fish movements, and appropriate habitat needs of plant and animal communities. Lake-levels should not be controlled and stabilized by dams or augmentation wells. Natural seasonal and long-term water fluctuations are important to preserve abundance and diversity of vegetation, spawning and nursery areas for fish and wildlife, and to prevent shoreline erosion. Beaver and beaver dam removal for "nuisance purposes" must be critically examined considering their value for deadwood and nutrient inputs and the creation of habitat beneficial to many species of wildlife.

*Non-indigenous Species*

Regulatory agencies should continue to implement existing regulations pertaining to the importation of non-indigenous species into Michigan, and more stringent regulations should be developed. The commercial shipping industry should be regulated to prevent any new invaders from entering the Great Lakes basin. Local agencies and groups should be encouraged to post educational materials at access sites to prevent introductions into inland water bodies.

*Research*

Human development activities, and how they affect the basic processes that preserve the ecological integrity of Michigan lakes, are the greatest threat to protecting natural resource public trusts and sustaining the resources of our lakes for future generations. Scientific information is paramount in understanding lake ecosystems and forms the basis for resource management. Historically, research activities have established general relationships between plants and animals and their habitats. Only recently have studies established cause-and-effect relationships between human development activities and natural resources. These types of studies are critical for regulatory protection efforts and necessary to support legal litigation. Development continues to expand in Michigan and it is imperative that adequate research be conducted to support management, education, regulatory, and judicial initiatives for Michigan lakes. Recommended areas of research are listed below:

- Determine the cumulative effects of development on the ecological integrity and biological communities of Michigan lakes.
- Determine appropriate management and research sampling programs for aquatic plants, shoreline vegetation, amphibians, reptiles, mollusks, mammals and birds.
- Determine the effectiveness of swimmers itch control programs.
- Determine the effects of copper introductions into lakes.
- Determine the effects of plant control programs on native and non-indigenous plants.

## Acknowledgements

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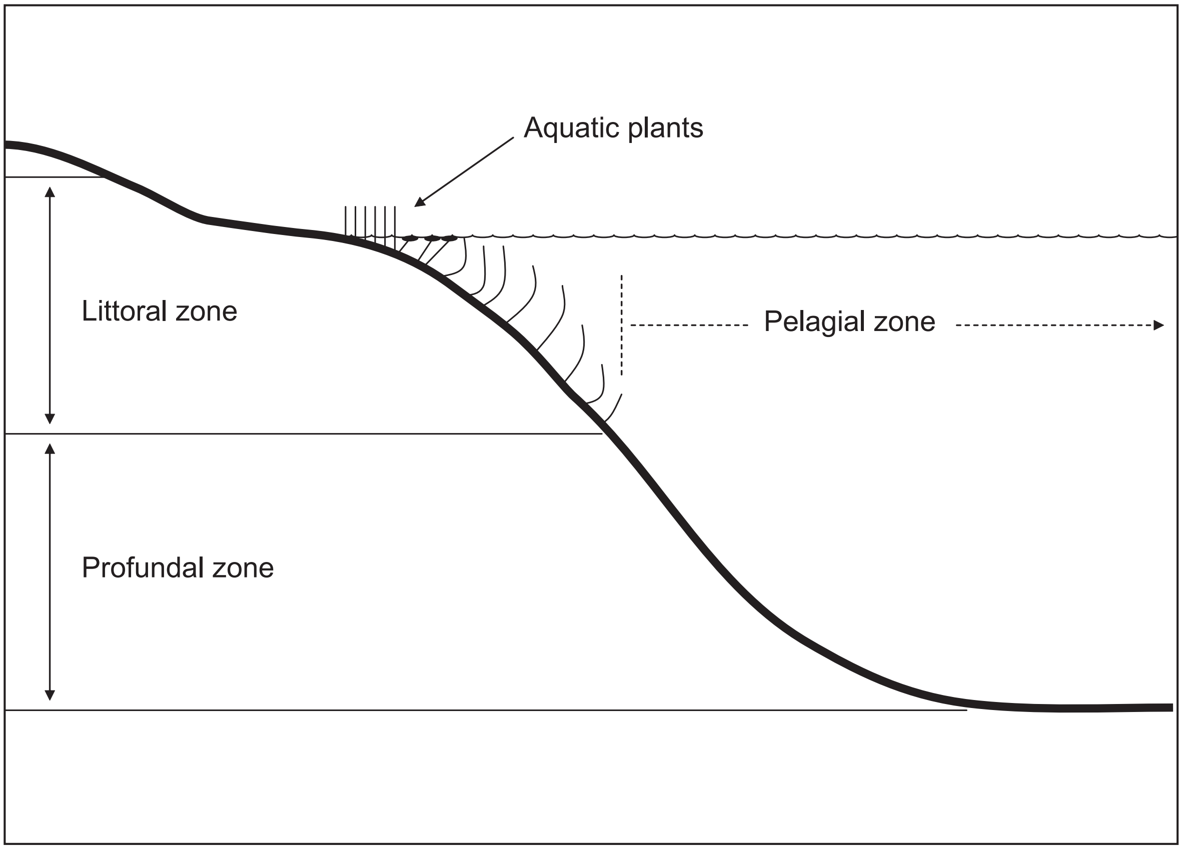


Figure 1.–Lacustrine zones (adapted from Wetzel 1975).

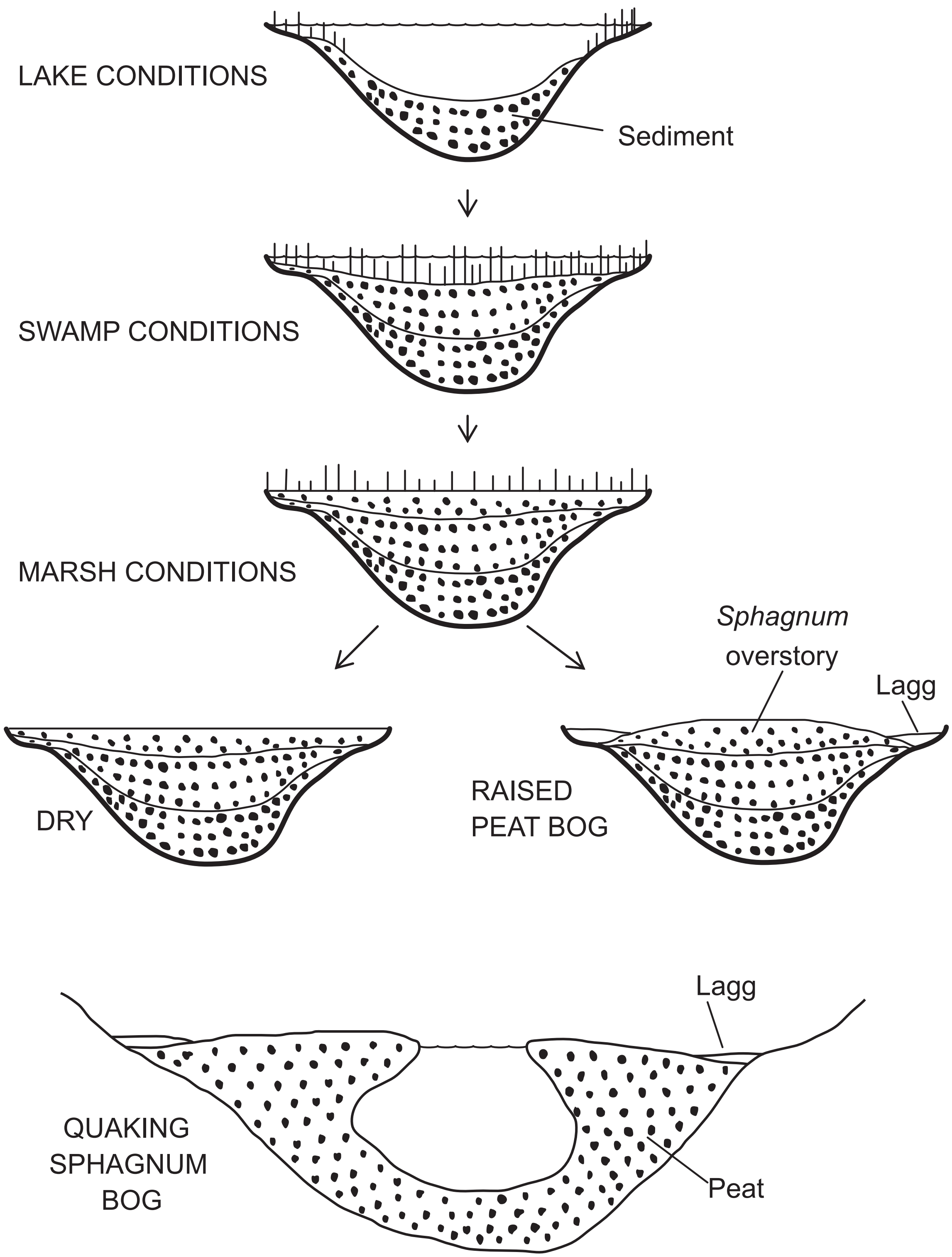


Figure 2.–Frequently observed ontogeny of shallow lake systems through swamp and marsh stages to dry landscape or to raised peat bogs (adapted from Wetzel 1975).

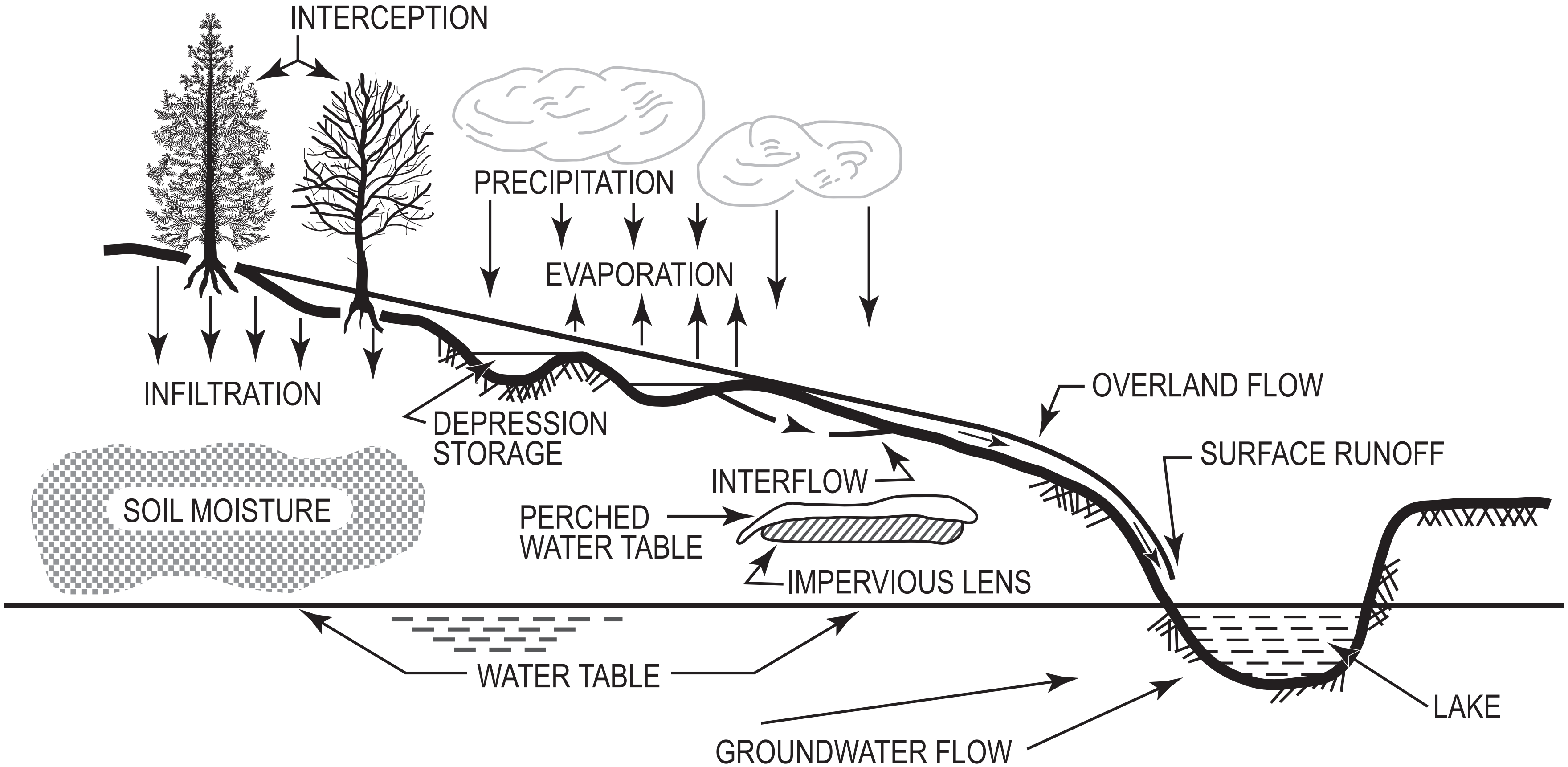


Figure 3.–Representation of the major pathways of the runoff phase of the hydrological cycle (adapted from Wetzel 1975).

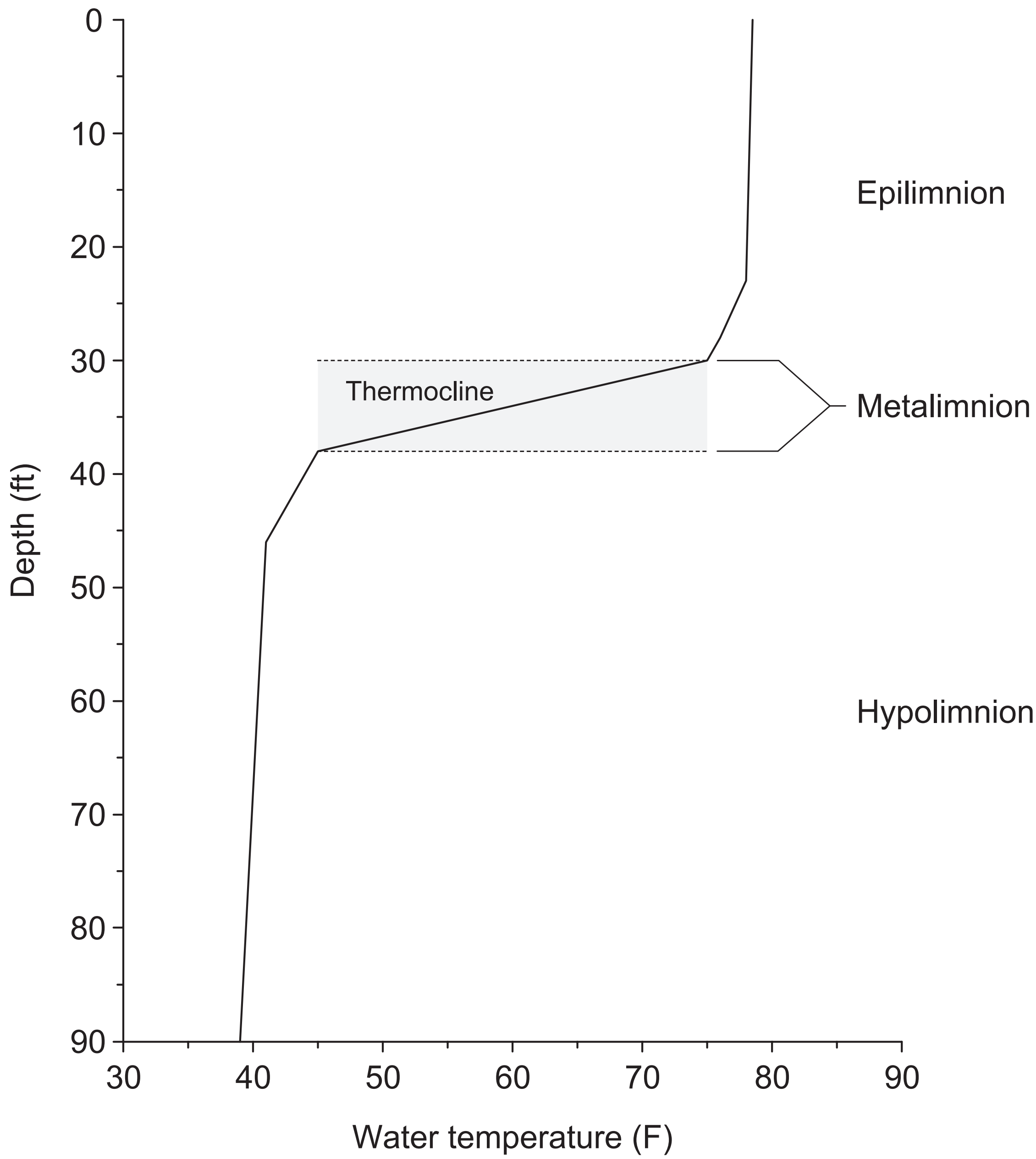


Figure 4.–Typical thermal stratification of a lake (adapted from Wetzel 1975).

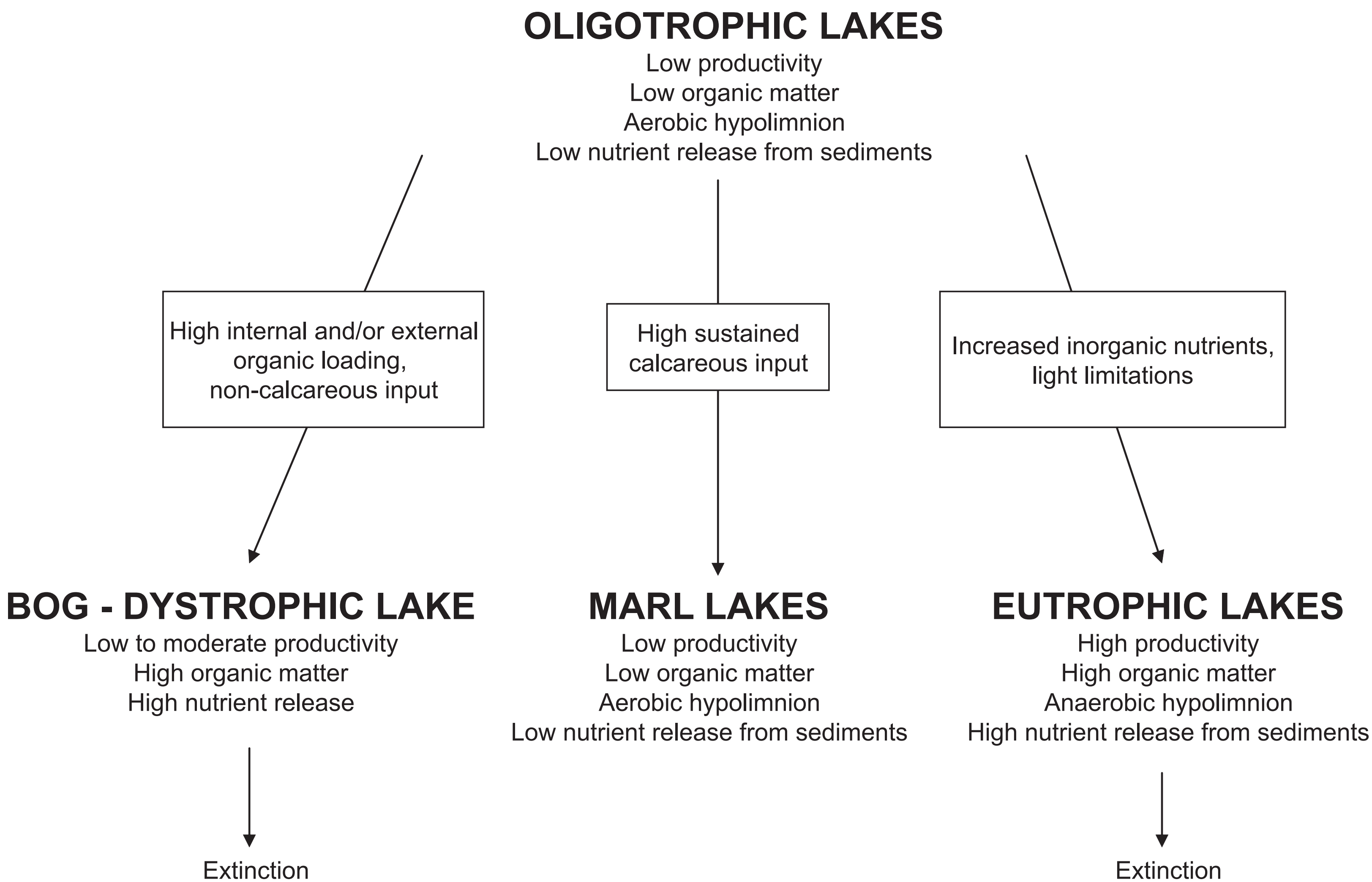


Figure 5.–Common ontogeny of four main types of lakes, each indicating general causal mechanisms regulating the trophic state (adapted from Wetzel 1975).

Table 1.–Water chemistry values for lakes in the Upper Peninsula of Michigan (EPA Subregion 2B) and the upper Great Lakes area (EPA Subregion 2D, which includes the northern Lower Peninsula of Michigan)[1]. Water sampling and analysis were conducted by the U.S. Environmental Protection Agency for the National Acid Precipitation Assessment Program. Only lakes at least 4 hectares (9.9 acres) in surface area were sampled. Values are shown for the 20$^{th}$ percentile, the 50$^{th}$ percentile (median), and the 80$^{th}$ percentile, as reported in Linthurst et al. (1986); some units were converted from $\mu eq \cdot L^{-1}$ to $mg \cdot L^{-1}$.

| | | Upper Peninsula | | | Northern Lower Peninsula | | |
|---|---|---|---|---|---|---|---|
| Variable | Units | 20th | 50th | 80th | 20th | 50th | 80th |
| pH | | 6.07 | 7.10 | 7.82 | 6.63 | 7.39 | 8.07 |
| ANC[2] | µeq/L | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| DOC[3] | mg/L | 3.4 | 6.8 | 11.2 | 5.2 | 8.8 | 13.0 |
| Ext. Al[4] | µg/L | 0.0 | 3.0 | 11.9 | 0.2 | 3.3 | 8.2 |
| Sulfate | mg/L | 2.4 | 3.7 | 5.0 | 1.4 | 2.4 | 4.1 |
| Calcium | mg/L | 1.7 | 4.9 | 19.4 | 1.8 | 10.5 | 23.8 |
| Nitrate | mg/L | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.2 |
| Ammonium | mg/L | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 |
| Phosphate-total | µg/L | 6.8 | 12.6 | 18.8 | 9.8 | 18.9 | 31.1 |
| True color | PCU | 16 | 31 | 74 | 15 | 39 | 74 |
| Turbidity | NTU | 0.6 | 0.9 | 1.6 | 0.5 | 1.0 | 2.0 |
| Secchi depth | feet | 3.0 | 4.9 | 9.5 | 3.3 | 6.2 | 10.8 |
| Sodium | mg/L | 0.3 | 0.7 | 1.1 | 0.5 | 1.5 | 2.7 |
| Potassium | mg/L | 0.3 | 0.5 | 0.8 | 0.6 | 0.8 | 1.2 |
| Magnesium | mg/L | 0.5 | 1.8 | 5.1 | 0.8 | 4.1 | 8.5 |
| Iron | µg/L | 13.8 | 49.9 | 201.2 | 2.1 | 44.0 | 196.6 |
| Manganese | µg/L | 0.0 | 0.0 | 20.4 | 0.0 | 0.0 | 9.1 |
| Aluminum-total | µg/L | 12.5 | 30.9 | 107.6 | 8.0 | 19.7 | 48.1 |
| Silica | mg/L | 0.3 | 2.3 | 6.1 | 0.3 | 2.4 | 9.0 |
| DIC5 | mg/L | 1.0 | 4.5 | 14.8 | 1.7 | 9.5 | 22.1 |
| Chloride | mg/L | 0.2 | 0.4 | 0.8 | 0.4 | 0.8 | 3.8 |
| Conductance | µS/cm | 20.5 | 47.2 | 132.9 | 24.7 | 91.6 | 198.7 |
| Bicarbonate | mg/L | 1.8 | 16.8 | 70.7 | 4.3 | 46.5 | 115.9 |

[1] Sampling in Michigan conducted from October 9 to November 6, 1984. Subregion 2B included 133 Michigan lakes and 13 Wisconsin lakes. Subregion 2D included 10 Michigan lakes and 131 Wisconsin and Minnesota lakes.
[2] Acid Neutralizing Capacity.
[3] Dissolved Organic Carbon.
[4] Extractable Aluminum.
[5] Dissolved Inorganic Carbon.

Table 2.–Classification of water based on hardness (Shaw et al. 1996).

| Hardness level | Concentration (mg/l) |
|---|---|
| Soft | 0–60 |
| Moderate | 61–120 |
| Hard | 121–180 |
| Very hard | >180 |

Table 3.–Water quality parameters in relation to trophic status (Carlson 1977).

| Lake trophic state | Phosphorus (mg/l) | Transparency (Secchi disk, ft) | Chloropyll-a (mg/l) |
|---|---|---|---|
| Oligotrophic | <0.010 | >15.0 | <0.0020 |
| Mesotrophic | 0.010–0.030 | 6.0–15.0 | 0.0020–0.010 |
| Eutrophic | >0.030 | <6.0 | >0.010 |

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Appendix 1.–Plants that are nearly always (>99% probability) found in Michigan lacustrine habitats. Table adapted from Herman et al. (2001). PHYS = physiognomy, C = coefficient of conservatism[1], M = monocotyledon, D = dicotyledon, S/FL = submergent or floating leaf plant[2], F = fern or ally, Nt = native taxa, Ad = adventive taxa, A = annual, B = biennial, P = perennial. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern. Parenthetical scientific names indicate former names.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Acanthus Family | Acanthaceae | | | | |
| Water-willow (T) | *Justicia americana* | Nt P-Forb | 9 | D | |
| Water-plantain Family | Alismataceae | | | M | |
| Water-plantain | *Alisma plantago-aquatica* | Nt P-Forb | 1 | M | Y |
| Dwarf burhead (En) | *Echinodorus tenellus (E. parvulus)* | Nt P-Forb | 10 | M | Y |
| Short-beaked arrowhead | *Sagittaria brevirostra* | Nt P-Forb | 10 | M | Y |
| Arum-leaved arrowhead | *Sagittaria cuneata* | Nt P-Forb | 6 | M | Y |
| Grass-leaved arrowhead | *Sagittaria graminea* | Nt P-Forb | 10 | M | Y |
| Common arrowhead | *Sagittaria latifolia* | Nt P-Forb | 1 | M | Y |
| Arrowhead (T) | *Sagittaria montevidensis (Lophotocarpus calycinus)* | Nt A-Forb | 8 | M | Y |
| Stiff arrowhead | *Sagittaria rigida* | Nt P-Forb | 6 | M | Y |
| Amaranth Family | Amaranthaceae | | | D | |
| Water-hemp | *Amaranthus tuberculatus* | Nt A-Forb | 6 | D | |
| Cashew Family | Anacardiaceae | | | D | |
| Poison sumac | *Toxicodendron vernix* | Nt Shrub | 6 | D | |
| Carrot or Parsley Family | Apiaceae | | | D | |
| Angelica | *Angelica atropurpurea* | Nt P-Forb | 6 | D | |
| Water-parsnip (T) | *Berula erecta (B. pusilla)* | Nt P-Forb | 10 | D | |
| Water hemlock | *Cicuta bulbifera* | Nt P-Forb | 5 | D | |
| Water hemlock | *Cicuta maculata* | Nt B-Forb | 4 | D | |
| Hemlock parsley | *Conioselinum chinense* | Nt P-Forb | 10 | D | |
| Water-pennywort | *Hydrocotyle americana* | Nt P-Forb | 6 | D | |
| Water-pennywort | *Hydrocotyle umbellata* | Nt P-Forb | 10 | D | |
| Cowbane | *Oxypolis rigidior* | Nt P-Forb | 6 | D | |
| Water-parsnip | *Sium suave* | Nt P-Forb | 5 | D | Y |
| Holly Family | Aquifoliaceae | | | D | |
| Mountain holly | *Nemopanthus mucronatus* | Nt Shrub | 7 | D | |
| Arum Family | Araceae | | | M | |
| Sweet-flag | *Acorus calamus* | Nt P-Forb | 6 | M | |
| Wild calla | *Calla palustris* | Nt P-Forb | 10 | M | |
| Arrow-arum | *Peltandra virginica* | Nt P-Forb | 6 | M | |
| Skunk-cabbage | *Symplocarpus foetidus* | Nt P-Forb | 6 | M | |
| Milkweed Family | Asclepiadaceae | | | D | |
| Swamp milkweed | *Asclepias incarnata* | Nt P-Forb | 6 | D | |
| Aster or Daisy Family | Asteraceae (Compositae) | | | D | |
| Northern bog-aster | *Aster borealis* | Nt P-Forb | 9 | D | |
| Smooth swamp aster | *Aster firmus (A. lucidulus)* | Nt P-Forb | 4 | D | |
| Bog aster | *Aster nemoralis* | Nt P-Forb | 10 | D | |
| Swamp aster | *Aster puniceus (A. lucidulus)* | Nt P-Forb | 5 | D | |
| Small salt-marsh aster * | *Aster subulatus* | Ad A-Forb | * | D | |
| Nodding bur-marigold | *Bidens cernuus* | Nt A-Forb | 3 | D | |
| Purple-stemmed tickseed | *Bidens connatus* | Nt A-Forb | 5 | D | |
| Tall swamp-marigold | *Bidens coronatus* | Nt A-Forb | 7 | D | |
| Swamp-thistle | *Cirsium muticum* | Nt B-Forb | 6 | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Common cosmos * | *Cosmos bipinnatus* | Ad A-Forb | * | D | |
| Orange cosmos * | *Cosmos sulphureus* | Ad A-Forb | * | D | |
| Yerba-de-tajo | *Eclipta prostrata* | Nt A-Forb | 4 | D | |
| Hollow Joe-pye-weed (T) | *Eupatorium fistulosum* | Nt P-Forb | 10 | D | |
| Joe-pye-weed | *Eupatorium maculatum* | Nt P-Forb | 4 | D | |
| Water marigold | *Megalodonta beckii (Bidens b.)* | Nt P-Forb | 10 | D | Y |
| Butterfly-dock * | *Petasites hybridus* | Ad P-Forb | * | D | |
| Sweet coltsfoot (T) | *Petasites sagittatus* | Nt P-Forb | 10 | D | |
| Black-eyed susan (Sc) | *Rudbeckia fulgida (R. sullivantii)* | Nt P-Forb | 9 | D | |
| Houghton's goldenrod (T) | *Solidago houghtonii* | Nt P-Forb | 10 | D | |
| Ohio goldenrod | *Solidago ohioensis* | Nt P-Forb | 8 | D | |
| Swamp goldenrod | *Solidago patula* | Nt P-Forb | 6 | D | |
| Riddell's goldenrod | *Solidago riddellii* | Nt P-Forb | 6 | D | |
| Bog goldenrod | *Solidago uliginosa* | Nt P-Forb | 4 | D | |
| Birch Family | Betulaceae | | | D | |
| Tag alder | *Alnus rugosa* | Nt Shrub | 5 | D | |
| Bog birch | *Betula pumila* | Nt Shrub | 8 | D | |
| Fern Family | Blechnaceae | | | F | |
| Netted chain-fern (Ep) | *Woodwardia areolata* | Nt Fern | 10 | F | |
| Virginia chain-fern | *Woodwardia virginica* | Nt Fern | 10 | F | |
| Borage Family | Boraginaceae | | | D | |
| Forget-me-not | *Myosotis laxa* | Nt P-Forb | 6 | D | |
| Small forget-me-not * | *Myosotis laxa* | Ad P-Forb | * | D | |
| Mustard Family | Brassicaceae (Cruciferae) | | | D | |
| Lake cress (T) | *Armoracia lacustris (A. aquatica)* | Nt P-Forb | 8 | D | Y |
| Northern winter cress | *Barbarea orthoceras* | Nt B-Forb | 10 | D | |
| Spring cress | *Cardamine bulbosa* | Nt P-Forb | 4 | D | |
| Cuckoo flower | *Cardamine pratensis* | Nt P-Forb | 10 | D | |
| Watercress * | *Nasturtium officinale* | Ad P-Grass | * | D | |
| Yellow cress | *Rorippa palustris* | Nt A-Forb | 1 | D | |
| Creeping yellow cress * | *Rorippia sylvestris* | Ad P-Forb | * | D | |
| Awlwort (En) | *Subularia aquatica* | Nt A-Forb | 10 | D | Y |
| Flowering-rush Family | Butomaceae | | | M | |
| Fowering-rush * | *Butomus umbellatus* | Ad P-Forb | * | M | |
| Water-starwort Family | Callitrichaceae | | | D | |
| Autumnal water-starwort (Sc) | *Callitriche hermaphroditica* | Nt A-Forb | 9 | D | Y |
| Large water-starwort (T) | *Callitriche heterophylla* | Nt A-Forb | 9 | D | Y |
| Water-starwort | *Callitriche verna (C. palustris)* | Nt P-Forb | 6 | D | Y |
| Bellflower Family | Campanulaceae | | | D | |
| Marsh bellflower | *Campanula aparinoides* | Nt P-Forb | 7 | D | |
| Marsh bellflower | *Campanula aparinoides ssp. uliginosa* | Nt P-Forb | 7 | D | |
| Cardinal flower | *Lobelia cardinalis* | Nt P-Forb | 7 | D | |
| Water lobelia | *Lobelia dortmanna* | Nt P-Forb | 10 | D | Y |
| Bog lobelia | *Lobelia kalmii* | Nt P-Forb | 10 | D | |
| Honeysuckle Family | Caprifoliaceae | | | D | |
| Swamp fly honeysuckle | *Lonicera oblongifolia* | Nt Shrub | 8 | D | |
| Pink Family | Caryophyllaceae | | | D | |
| Sant spurry * | *Spergularia marina* | Ad A-Forb | * | D | |
| Northern stitchwort | *Stellaria borealis* | Nt P-Forb | 10 | D | |
| Starwort (Sc) | *Stellaria longipes* | Nt P-Forb | 10 | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Hornwort Family | Ceratophyllaceae | | | D | |
| Coontail | *Ceratophyllum demersum* | Nt P-Forb | 1 | D | Y |
| Spiny hornwort | *Ceratophyllum echinatum* | Nt P-Forb | 10 | D | Y |
| Goosefoot Family | Chenopodiaceae | | | D | |
| Coast blight * | *Chenopodium rubrum* | Ad A-Forb | * | D | |
| Glasswort * | *Salicornia europaea* | Ad A-Forb | * | D | |
| Sedge Family | Cyperaceae | | | M | |
| Bulrush | *Bolboschoenus fluviatilis (Scirpus f.)* | Nt P-Sedge | 6 | M | |
| Bulrush* | *Bolboschoenus maritimus (Scirpus paludosus)* | Ad P-Sedge | * | M | |
| Sedge* | *Carex acutiformis* | Ad P-Sedge | * | M | |
| Winged sedge | *Carex alata* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex aquatilis* | Nt P-Sedge | 7 | M | |
| Sedge | *Carex arcta* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex atherodes* | Nt P-Sedge | 5 | M | |
| Sedge | *Carex bebbii* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex buxbaumii* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex canescens* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex chordorrhiza* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex comosa* | Nt P-Sedge | 5 | M | |
| Sedge (T) | *Carex crus-corvi* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex cryptolepis* | Nt P-Sedge | 10 | M | |
| Log sedge (Ep) | *Carex decomposita* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex diandra* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex disperma* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex echinata (cephalantha/angustior)* | Nt P-Sedge | 6 | M | |
| Sedge | *Carex emoryi* | Nt P-Sedge | 7 | M | |
| Sedge | *Carex exilis* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex flava* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex folliculata* | Nt P-Sedge | 10 | M | |
| Frank's sedge (Sc) | *Carex frankii* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex gynocrates* | Nt P-Sedge | 10 | M | |
| Hayden's sedge (Ep) | *Carex haydenii* | Nt P-Sedge | 8 | M | |
| Sedge (En) | *Carex heleonastes* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex hyalinolepis* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex hystericina* | Nt P-Sedge | 2 | M | |
| Sedge | *Carex interior* | Nt P-Sedge | 3 | M | |
| Sedge | *Carex lacustris* | Nt P-Sedge | 6 | M | |
| Sedge | *Carex laevivaginata* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex lasiocarpa* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex lenticularis* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex leptalea* | Nt P-Sedge | 5 | M | |
| Bog sedge | *Carex limosa* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex livida* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex longii* | Nt P-Sedge | 6 | M | |
| Sedge | *Carex lupulina* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex lurida* | Nt P-Sedge | 3 | M | |
| Sedge | *Carex michauxiana* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex muskingumensis* | Nt P-Sedge | 6 | M | |
| Black sedge (En) | *Carex nigra* | Nt P-Sedge | 7 | M | |
| Sedge | *Carex oligosperma* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex pauciflora* | Nt P-Sedge | 10 | M | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Sedge | *Carex paupercula* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex pellita (C. lanuginosa)* | Nt P-Sedge | 2 | M | |
| Sedge | *Carex prasina* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex pseudo-cyperus* | Nt P-Sedge | 5 | M | |
| Sedge | *Carex retrorsa* | Nt P-Sedge | 3 | M | |
| Sedge | *Carex rostrata* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex scabrata* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex schweinitzii* | Nt P-Sedge | 10 | M | |
| Sedge (Sc) | *Carex squarrosa* | Nt P-Sedge | 9 | M | |
| Sedge | *Carex sterilis* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex stipata* | Nt P-Sedge | 1 | M | |
| Straw sedge (En) | *Carex straminea* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex stricta* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex suberecta* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex tenuiflora* | Nt P-Sedge | 10 | M | |
| Hairy-fruited sedge (Sc) | *Carex trichocarpa* | Nt P-Sedge | 8 | M | |
| Sedge | *Carex trisperma* | Nt P-Sedge | 9 | M | |
| Sedge | *Carex tuckermanii* | Nt P-Sedge | 8 | M | |
| Cat-tail sedge (T) | *Carex typhina* | Nt P-Sedge | 9 | M | |
| Sedge | *Carex utriculata* | Nt P-Sedge | 5 | M | |
| Sedge | *Carex vaginata* | Nt P-Sedge | 10 | M | |
| Sedge | *Carex vesicaria* | Nt P-Sedge | 7 | M | |
| Sedge | *Carex viridula* | Nt P-Sedge | 4 | M | |
| Sedge | *Carex vulpinoidea* | Nt P-Sedge | 1 | M | |
| Wiegand's sedge (T) | *Carex wiegandii* | Nt P-Sedge | 9 | M | |
| Twig-rush | *Cladium mariscoides* | Nt P-Sedge | 10 | M | |
| Umbrella sedge (Ep) | *Cyperus acuminatus* | Nt A-Sedge | 6 | M | |
| Umbrella sedge | *Cyperus engelmannii* | Nt A-Sedge | 4 | M | |
| Umbrella sedge | *Cyperus erythrorhizos* | Nt A-Sedge | 6 | M | |
| Yellow flat sedge (S) | *Cyperus flavescens* | Nt A-Sedge | 5 | M | |
| Umbrella sedge | *Cyperus squarrosus (C. aristatus)* | Nt A-Sedge | 5 | M | |
| Three-way sedge | *Dulichium arundinaceum* | Nt P-Sedge | 8 | M | |
| Spike-rush | *Eleocharis acicularis* | Nt P-Sedge | 7 | M | Y |
| Purple spike-rush (En) | *Eleocharis atropurpurea* | Nt A-Sedge | 9 | M | |
| Horsetail spike-rush (Sc) | *Eleocharis equisetoides* | Nt P-Sedge | 9 | M | |
| Spike-rush | *Eleocharis erythropoda* | Nt P-Sedge | 4 | M | |
| Small fruited spike-rush (En) | *Eleocharis microcarpa* | Nt A-Sedge | 10 | M | |
| Slender spike-rush (En) | *Eleocharis nitida* | Nt P-Sedge | 10 | M | |
| Spike-rush | *Eleocharis obtusa* | Nt A-Sedge | 3 | M | |
| Spike-rush | *Eleocharis olivacea* | Nt P-Sedge | 7 | M | |
| Spike-rush | *Eleocharis ovata* | Nt A-Sedge | 8 | M | |
| Dwarf spike-rush (T) | *Eleocharis parvula* | Nt P-Sedge | 10 | M | |
| Four-sided spike-rush | *Eleocharis quadrangulata* | Nt P-Sedge | 8 | M | |
| Spike-rush | *Eleocharis quinqueflora (E. pauciflora)* | Nt P-Sedge | 10 | M | |
| Spike rush (Ep) | *Eleocharis radicans* | Nt P-Sedge | 10 | M | |
| Spike-rush | *Eleocharis robbinsii* | Nt P-Sedge | 8 | M | Y |
| Spike-rush | *Eleocharis rostellata* | Nt P-Sedge | 10 | M | |
| Spike-rush | *Eleocharis smallii* | Nt P-Sedge | 5 | M | |
| Three-ribbed spike-rush (T) | *Eleocharis tricostata* | Nt P-Sedge | 10 | M | |
| Narrow-leaved cotton-grass | *Eriophorum angustifolium* | Nt P-Sedge | 10 | M | |
| Slender cotton-grass | *Eriophorum gracile* | Nt P-Sedge | 10 | M | |
| Cotton-grass | *Eriophorum spissum* | Nt P-Sedge | 10 | M | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Cotton-grass | *Eriophorum tenellum* | Nt P-Sedge | 10 | M | |
| Tawny cotton-grass | *Eriophorum virginicum* | Nt P-Sedge | 8 | M | |
| Green-keeled cotton-grass | *Eriophorum viridi-carinatum* | Nt P-Sedge | 8 | M | |
| Chestnut sedge (Ep) | *Fimbristylis puberula* | Nt P-Sedge | 10 | M | |
| Umbrella-grass (T) | *Fuirena squarrosa (F. pumila)* | Nt P-Sedge | 10 | M | |
| Dwarf-bulrush (Sc) | *Hemicarpha micrantha (Lipocarpa m.)* | Nt A-Sedge | 7 | M | |
| Bald-rush | *Psilocarya nitens* | Nt A-Sedge | 10 | M | |
| Bald-rush (T) | *Psilocarya scirpoides* | Nt A-Sedge | 10 | M | |
| Bald-rush | *Rhynchospora alba* | Nt P-Sedge | 6 | M | |
| Bald-rush | *Rhynchospora capillacea* | Nt P-Sedge | 10 | M | |
| Bald-rush | *Rhynchospora capitellata* | Nt P-Sedge | 6 | M | |
| Bald-rush | *Rhynchospora fusca* | Nt P-Sedge | 7 | M | |
| Tall beak-rush (Sc) | *Rhynchospora macrostachya* | Nt P-Sedge | 9 | M | |
| Short-beaked bald-rush | *Rhyncospora nitens (Psilocarya n.)* | Nt A-Sedge | 10 | M | |
| Hardstem bulrush | *Schoenoplectus acutus (Scirpus a.)* | Nt P-Sedge | 5 | M | |
| Olney's bulrush (T) | *Schoenoplectus americanus (Scirpus olneyi)* | Nt P-Sedge | 10 | M | |
| Hall's bulrush (T) | *Schoenoplectus hallii (Scirpus h.)* | Nt A-Sedge | 10 | M | |
| Bulrush | *Schoenoplectus heterochaetus (Scirpus h.)* | Nt P-Sedge | 10 | M | |
| Three-sqaure | *Schoenoplectus pungens (Scirpus americanus)* | Nt P-Sedge | 5 | M | |
| Pursh's tufted bulrush | *Schoenoplectus purshianus (Scirpus p.)* | Nt A-Sedge | 8 | M | |
| Bulrush | *Schoenoplectus smithii (Scirpus s.)* | Nt A-Sedge | 8 | M | |
| Bulrush | *Schoenoplectus subterminalis (Scirpus s.)* | Nt P-Sedge | 8 | M | Y |
| Softstem bulrush | *Schoenoplectus tabernaemontani (Scirpus validus)* | Nt P-Sedge | 4 | M | |
| Torrey's bulrush (Sc) | *Schoenoplectus torreyi (Scirpus t.)* | Nt P-Sedge | 10 | M | |
| Bulrush | *Scirpus atrovirens* | Nt P-Sedge | 3 | M | |
| Wool-grass | *Scirpus cyperinus* | Nt P-Sedge | 5 | M | |
| Bulrush | *Scirpus expansus* | Nt P-Sedge | 5 | M | |
| Mosquito bulrush | *Scirpus hattorianus* | Nt P-Sedge | 3 | M | |
| Bulrush | *Scirpus microcarpus* | Nt P-Sedge | 5 | M | |
| Bulrush | *Scirpus pendulus* | Nt P-Sedge | 3 | M | |
| Netted nut-rush (T) | *Scleria reticularis* | Nt A-Sedge | 10 | M | |
| Nut-rush | *Scleria verticillata* | Nt A-Sedge | 10 | M | |
| Bulrush | *Trichophorum alpinum (Scirpus hudsonianus)* | Nt P-Sedge | 10 | M | |
| Bulrush | *Trichophorum cespitosum (Scirpus cespitosus)* | Nt P-Sedge | 10 | M | |
| Sundew Family | Droseraceae | | | D | |
| Sundew | *Drosera intermedia* | Nt P-Forb | 8 | D | |
| Linear-leaved sundew | *Drosera linearis* | Nt P-Forb | 10 | D | |
| Round-leaved sundew | *Drosera rotundifolia* | Nt P-Forb | 6 | D | |
| English sundew (Sc) | *Drosera Xanglica* | Nt P-Forb | 10 | D | |
| Waterwort Family | Elatinaceae | | | D | |
| Waterwort | *Elatine minima* | Nt A-Forb | 10 | D | Y |
| Horsetail Family | Equisetaceae | | | F | |
| Water horsetail | *Equisetum fluviatile* | Nt Fern Ally | 7 | FA | Y |
| Giant horsetail (Ep) | *Equisetum telmateia* | Nt Fern Ally | 10 | FA | |
| Heath Family | Ericaceae | | | D | |
| Bog rosemary | *Andromeda glaucophylla* | Nt Shrub | 10 | D | |
| Leatherleaf | *Chamaedaphne calyculata* | Nt Shrub | 8 | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Swamp-laurel | *Kalmia polifolia* | Nt Shrub | 10 | D | |
| Labrador-tea | *Ledum groenlandicum* | Nt Shrub | 8 | D | |
| Large cranberry | *Vaccinium macrocarpon* | Nt Shrub | 8 | D | |
| Small cranberry | *Vaccinium oxycoccos* | Nt Shrub | 8 | D | |
| Pipewort Family | Eriocaulaceae | | | M | |
| Pipewort | *Eriocaulon septangulare* | Nt P-Forb | 9 | M | Y |
| Gentian Family | Gentianaceae | | | D | |
| Panicled screw-stem (T) | *Bartonia paniculata* | Nt A-Forb | 10 | D | |
| Great Lakes gentian | *Gentiana rubricaulis* | Nt P-Forb | 7 | D | |
| Small fringed gentian | *Gentianopsis procera (Gentiana p.)* | Nt A-Forb | 8 | D | |
| Buckbean | *Menyanthes trifoliata* | Nt P-Forb | 8 | D | |
| Gooseberry Family | Grossulariaceae | | | D | |
| Northern black currant | *Ribes hudsonianum* | Nt Shrub | 10 | D | |
| Swamp red currant | *Ribes triste* | Nt Shrub | 6 | D | |
| St. John's-wort Family | Guttiferae | | | D | |
| Northern St. John's-wort | *Hypericum boreale* | Nt P-Forb | 5 | D | Y |
| Pale St. John's-wort | *Hypericum ellipticum* | Nt P-Forb | 9 | D | |
| Marsh St. John's-wort | *Triadenum fraseri (Hypericum f.)* | Nt P-Forb | 6 | D | |
| Marsh St. John's-wort | *Triadenum virginicum (Hypericum v.)* | Nt P-Forb | 10 | D | |
| Water-milfoil Family | Haloragaceae | | | D | |
| Alternate-leaved water-milfoil (Sc) | *Myriophyllum alterniflorum* | Nt P-Forb | 10 | D | Y |
| Spiked water-milfoil | *Myriophyllum exalbescens* | Nt P-Forb | 10 | D | Y |
| Farwell's water-milfoil (T) | *Myriophyllum farwellii* | Nt P-Forb | 10 | D | Y |
| Various-leaved water-milfoil | *Myriophyllum heterophyllum* | Nt P-Forb | 6 | D | Y |
| Eurasian water-milfoil * | *Myriophyllum spicatum* | Ad P-Forb | * | D | Y |
| Water-milfoil | *Myriophyllum tenellum* | Nt P-Forb | 10 | D | Y |
| Water-milfoil | *Myriophyllum verticillatum* | Nt P-Forb | 6 | D | Y |
| Mermaid weed | *Proserpinaca palustris* | Nt P-Forb | 6 | D | Y |
| Mermaid weed (E) | *Proserpinaca pectinata* | Nt P-Forb | 9 | D | Y |
| Mare’s-tail Family | Hippuridaceae | | | | |
| Mare's-tail | *Hippuris vulgaris* | Nt P-Forb | 10 | D | Y |
| Frog's-bit Family | Hydrocharitaceae | | | M | |
| Common waterweed | *Elodea canadensis* | Nt P-Forb | 1 | M | Y |
| Slender waterweed | *Elodea nuttallii* | Nt P-Forb | 5 | M | Y |
| European frog's-bit * | *Hydrocharis morsus-ranae* | Ad P-Forb | * | M | Y |
| Eel grass | *Vallisneria americana* | Nt P-Forb | 7 | M | Y |
| Iris Family | Iridaceae | | | M | |
| Yellow flag * | *Iris pseudacorus* | Ad P-Forb | * | M | |
| Wild blue flag | *Iris versicolor* | Nt P-Forb | 5 | M | |
| Southern blue flag | *Iris virginica* | Nt P-Forb | 5 | M | |
| Quillwort Family | Isoetaceae | | | F | |
| Quillwort | *Isoetes echinospora* | Nt Fern Ally | 8 | FA | Y |
| Quillwort | *Isoetes lacustris* | Nt Fern Ally | 8 | FA | Y |
| Rush Family | Juncaceae | | | M | |
| Sharp-fruited rush | *Juncus acuminatus* | Nt P-Forb | 8 | M | |
| Rush | *Juncus alpinus* | Nt P-Forb | 5 | M | |
| Jointed rush | *Juncus articulatus* | Nt P-Forb | 3 | M | |
| Rush | *Juncus balticus* | Nt P-Forb | 4 | M | |
| Rush | *Juncus brachycephalus* | Nt P-Forb | 7 | M | |
| Rush | *Juncus brevicaudatus* | Nt P-Forb | 8 | M | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Canadian rush | *Juncus canadensis* | Nt P-Forb | 6 | M | |
| Soft-stemmed rush | *Juncus effusus* | Nt P-Forb | 3 | M | |
| Black-grass * | *Juncus gerardii* | Ad P-Forb | * | M | |
| Soldier rush (T) | *Juncus militaris* | Nt P-Forb | 10 | M | Y |
| Joint rush | *Juncus nodosus* | Nt P-Forb | 5 | M | |
| Brown-fruited rush | *Juncus pelocarpus* | Nt P-Forb | 8 | M | Y |
| Arrow-grass Family | Juncaginaceae | | | M | |
| Arrow-grass | *Scheuchzeria palustris* | Nt P-Forb | 10 | M | |
| Common bog arrow-grass | *Triglochin maritimum* | Nt P-Forb | 8 | M | |
| Slender bog arrow-grass | *Triglochin palustre* | Nt P-Forb | 8 | M | |
| Mint Family | Lamiaceae (Labiatae) | | | D | |
| Common water horehound | *Lycopus americanus* | Nt P-Forb | 2 | D | |
| Rough water horehound * | *Lycopus asper* | Ad P-Forb | * | D | |
| European water horehound * | *Lycopus europaeus* | Ad P-Forb | * | D | |
| Stalked water horehound | *Lycopus rubellus* | Nt P-Forb | 8 | D | |
| Northern bugle weed | *Lycopus uniflorus* | Nt P-Forb | 2 | D | |
| Bugle weed (T) | *Lycopus virginicus* | Nt P-Forb | 8 | D | |
| Peppermint * | *Mentha piperita* | Ad P-Forb | * | D | |
| Broad-leaved mountain mint (T) | *Pycnanthemum muticum* | Nt P-Forb | 10 | D | |
| Common skullcap | *Scutellaria galericulata* | Nt P-Forb | 5 | D | |
| Mad-dog skullcap | *Scutellaria lateriflora* | Nt P-Forb | 5 | D | |
| Woundwort | *Stachys palustris* | Nt P-Forb | 5 | D | |
| South hedge nettle | *Stachys tenuifolia* | Nt P-Forb | 5 | D | |
| Duckweed Family | Lemnaceae | | | M | |
| Small duckweed | *Lemna minor* | Nt A-Forb | 5 | M | Y |
| Star duckweed | *Lemna trisulca* | Nt A-Forb | 6 | M | Y |
| Pale duckweed (Ep) | *Lemna valdiviana* | Nt A-Forb | 8 | M | Y |
| Great duckweed | *Spirodela polyrhiza* | Nt A-Forb | 6 | M | Y |
| Common water meal | *Wolffia columbiana* | Nt A-Forb | 5 | M | Y |
| Pointed water meal (T) | *Wolffia papulifera (W. brasiliensis)* | Nt P-Forb | 10 | M | Y |
| Dotted water meal | *Wolffia punctata* | Nt A-Forb | 5 | M | Y |
| Bladderwort Family | Lentibulariaceae | | | D | |
| Butterwort (Sc) | *Pinguicula vulgaris* | Nt P-Forb | 10 | D | |
| Horned bladderwort | *Utricularia cornuta* | Nt A-Forb | 10 | D | Y |
| Bog bladderwort | *Utricularia geminiscapa* | Nt P-Forb | 8 | D | Y |
| Humped bladderwort | *Utricularia gibba* | Nt P-Forb | 8 | D | Y |
| Flat-leaved bladderwort | *Utricularia intermedia* | Nt P-Forb | 10 | D | Y |
| small bladderwort | *Utricularia minor* | Nt P-Forb | 10 | D | Y |
| Purple bladderwort | *Utricularia purpurea* | Nt P-Forb | 10 | D | Y |
| Floating bladderwort (En) | *Utricularia radiata (U. inflata)* | Nt A-Forb | 10 | D | Y |
| Small purple bladderwort | *Utricularia resupinata* | Nt A-Forb | 10 | D | Y |
| Zigzag bladderwort (T) | *Utricularia subulata* | Nt A-Forb | 10 | D | Y |
| Great bladderwort | *Utricularia vulgaris* | Nt P-Forb | 6 | D | Y |
| Lily Family | Liliaceae | | | M | |
| False mayflower | *Smilacina trifolia* | Nt P-Forb | 10 | M | |
| False asphodel | *Tofieldia glutinosa* | Nt P-Forb | 10 | M | |
| Clubmoss Family | Lycopodiaceae | | | FA | |
| Bog clubmoss | *Lycopodiella inundata (Lycopodium i.)* | Nt Fern Ally | 7 | FA | |
| Loosestrife Family | Lythraceae | | | D | |
| Sessile tooth-cup | *Ammannia robusta* | Nt A-Forb | 6 | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Whorled or swamp loosestrife | *Decodon verticillatus* | Nt Shrub | 7 | D | |
| Winged loosestrife | *Lythrum alatum* | Nt P-Forb | 9 | D | |
| Hyssop loosestrife * | *Lythrum hyssopifolia* | Ad A-Forb | * | D | |
| Purple loosestrife * | *Lythrum salicaria* | Ad P-Forb | * | D | |
| Tooth-cup (Sc) | *Rotala ramosior* | Nt A-Forb | 8 | D | |
| Mallow Family | Malvaceae | | | D | |
| Smooth rose mallow (Sc) | *Hibiscus laevis* | Nt P-Forb | 7 | D | |
| Swamp rose mallow (Sc) | *Hibiscus moscheutos (H. palustris)* | Nt P-Forb | 7 | D | |
| Marsilea Family | Marsilaceae | | | FA | |
| European water-clover * | *Marsilea quadrifolia* | Ad Fern | * | FA | Y |
| Melastome Family | Melastomataceae | | | D | |
| Meadow beauty (Sc) | *Rhexia virginica* | Nt P-Forb | 9 | D | |
| Bayberry Family | Myricaceae | | | D | |
| Sweet gale | *Myrica gale* | Nt Shrub | 6 | D | |
| Naiad Family | Najadaceae | | | M | |
| Slender naiad | *Najas flexilis* | Nt A-Forb | 5 | M | Y |
| Naiad | *Najas gracillima* | Nt A-Forb | 8 | M | Y |
| Southern naiad | *Najas guadalupensis* | Nt A-Forb | 7 | M | Y |
| Spiny naiad * | *Najas marina* | Ad A-Forb | * | M | Y |
| Naiad * | *Najas minor* | Ad A-Forb | * | M | Y |
| Water-lily Family | Nymphaeaceae | | | D | Y |
| Watershield | *Brasenia schreberi* | Nt P-Grass | 6 | D | Y |
| Fanwort * | *Cabomba caroliniana* | Ad P-Forb | * | D | Y |
| American lotus (T) | *Nelumbo lutea* | Nt P-Forb | 8 | D | Y |
| Yellow pond-lily | *Nuphar advena* | Nt P-Forb | 8 | D | Y |
| Small yellow pond-lily (En) | *Nuphar pumila* | Nt P-Forb | 10 | D | Y |
| Yellow pond-lily | *Nuphar variegata* | Nt P-Forb | 7 | D | Y |
| Sweet-scented waterlily | *Nymphaea odorata (N. tuberosa)* | Nt P-Forb | 6 | D | Y |
| Pygmy pond-lily (En) | *Nymphaea tetragona* | Nt P-Forb | 10 | D | Y |
| Olive Family | Oleaceae | | | D | |
| Pumpkin ash (T) | *Fraxinus profunda* | Nt Tree | 9 | D | |
| Evening-primrose Family | Onagraceae | | | D | |
| Cinnamon willow-herb | *Epilobium coloratum* | Nt P-Forb | 3 | D | |
| Fen willow-herb | *Epilobium leptophyllum* | Nt P-Forb | 6 | D | |
| Marsh willow-herb | *Epilobium palustre* | Nt P-Forb | 10 | D | |
| Downy willow-herb | *Epilobium strictum* | Nt P-Forb | 8 | D | |
| Seedbox (Sc) | *Ludwigia alternifolia* | Nt P-Forb | 8 | D | |
| Water-purslane | *Ludwigia palustris* | Nt P-Forb | 4 | D | Y |
| False loosestrife | *Ludwigia polycarpa* | Nt P-Forb | 6 | D | |
| Round-fruited loosestrife (T) | *Ludwigia sphaerocarpa* | Nt P-Forb | 10 | D | |
| Orchid Family | Orchidaceae | | | M | |
| Round-leaved orchis (En) | *Amerorchis rotundifolia (Orchis r.)* | Nt P-Forb | 10 | M | |
| Dragon's mouth | *Arethusa bulbosa* | Nt P-Forb | 10 | M | |
| Grass-pink | *Calopogon tuberosus* | Nt P-Forb | 9 | M | |
| White lady's-slipper (T) | *Cypripedium candidum* | Nt P-Forb | 10 | M | |
| White-fringed orchid | *Platanthera blephariglottis (Habenaria b.)* | Nt P-Forb | 10 | M | |
| Rose pogonia | *Pogonia ophioglossoides* | Nt P-Forb | 10 | M | |
| Flowering Fern Family | Osmundaceae | | | F | |
| Royal fern | *Osmunda regalis* | Nt Fern | 5 | F | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Plantain Family | Plantaginaceae | | | D | |
| American shore-grass (Sc) | *Littorella uniflora var. americana (L. americana)* | Nt P-Forb | 10 | D | Y |
| Heart-leaved plantain (En) | *Plantago cordata* | Nt P-Forb | 10 | D | |
| Grass Family | Poaceae (Graminae) | | | M | |
| Short-awned foxtail | *Alopecurus aequalis* | Nt P-Grass | 4 | M | |
| Marsh foxtail * | *Alopecurus geniculatus* | Ad P-Grass | * | M | |
| Slough grass (T) | *Beckmannia syzigachne* | Nt A-Forb | 4 | M | |
| Blue-joint grass | *Calamagrostis canadensis* | Nt P-Grass | 3 | M | |
| Barnyard grass | *Echinochloa muricata* | Nt A-Grass | 1 | M | |
| Salt-marsh cockspur grass | *Echinochloa walteri* | Nt A-Grass | 7 | M | |
| Creeping love grass | *Eragrostis hypnoides* | Nt A-Grass | 8 | M | |
| Love grass * | *Eragrostis tephrosanthos* | Ad A-Grass | * | M | |
| Manna grass (Ep) | *Glyceria acutiflora* | Nt P-Grass | 10 | M | Y |
| Northern manna grass | *Glyceria borealis* | Nt P-Grass | 6 | M | Y |
| Rattlesnake grass | *Glyceria canadensis* | Nt P-Grass | 8 | M | Y |
| Reed manna grass | *Glyceria grandis* | Nt P-Grass | 6 | M | Y |
| Floating manna grass | *Glyceria septentrionalis* | Nt P-Grass | 7 | M | Y |
| Fowl manna grass | *Glyceria striata* | Nt P-Grass | 4 | M | Y |
| Cut grass | *Leersia oryzoides* | Nt P-Grass | 3 | M | |
| Sprangletop * | *Leptochloa fascicularis* | Ad A-Grass | * | M | |
| Muhly grass | *Muhlenbergia uniflora* | Nt P-Grass | 8 | M | |
| Panic grass | *Panicum lindheimeri* | Nt P-Grass | 8 | M | |
| Long-leaved panic grass (T) | *Panicum longifolium* | Nt P-Grass | 10 | M | |
| Panic grass | *Panicum spretum* | Nt P-Grass | 9 | M | |
| Bog bluegrass (T) | *Poa paludigena* | Nt P-Grass | 10 | M | |
| Rabbitfoot grass * | *Polypogon monspeliensis* | Ad A-Grass | * | M | |
| Alkali grass * | *Puccinellia distans* | Ad P-Grass | * | M | |
| Puccinellia | *Puccinellia fernaldii* | Nt P-Grass | 6 | M | |
| Puccinellia | *Puccinellia pallida* | Nt P-Grass | 7 | M | |
| Wild-rice (T) | *Zizania aquatica var. aquatica* | Nt A-Grass | 9 | M | Y |
| Wild-rice | *Zizania palustris (Z. aquatica var. angustifolia)* | Nt A-Grass | 8 | M | Y |
| Smartweed Family | Polygonaceae | | | D | |
| Water smartweed | *Polygonum amphibium* | Nt P-Forb | 6 | D | Y |
| Tear-thumb | *Polygonum arifolium* | Nt A-Forb | 7 | D | Y |
| Water pepper | *Polygonum hydropiper* | Nt A-Forb | 1 | D | Y |
| Water pepper | *Polygonum hydropiperoides* | Nt P-Forb | 5 | D | Y |
| Smartweed | *Polygonum punctatum* | Nt A-Forb | 5 | D | Y |
| Arrow-leaved tear-thumb | *Polygonum sagittatum* | Nt A-Forb | 5 | D | Y |
| Great water dock | *Rumex orbiculatus* | Nt P-Forb | 9 | D | Y |
| Water dock | *Rumex verticillatus* | Nt P-Forb | 7 | D | Y |
| Common Fern Family | Polypodiaceae | | | F | |
| Log fern (T) | *Dryopteris celsa* | Nt Fern | 10 | F | |
| Crested shield fern | *Dryopteris cristata* | Nt Fern | 6 | F | |
| Pickerel-weed Family | Pontederiaceae | | | M | |
| Water star-grass | *Heteranthera dubia* | Nt P-Forb | 6 | M | Y |
| Pickerel-weed | *Pontederia cordata* | Nt P-Forb | 8 | M | |
| Pondweed Family | Potamogetonaceae | | | M | |
| Pondweed | *Potamogeton alpinus* | Nt P-Forb | 10 | M | Y |
| Large-leaved pondweed | *Potamogeton amplifolius* | Nt P-Forb | 6 | M | Y |
| Berchtold's pondweed | *Potamogeton berchtoldii* | Nt P-Forb | 4 | M | Y |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Waterthread pondweed (T) | *Potamogeton bicupulatus (P. capillaceus)* | Nt P-Forb | 10 | M | Y |
| Alga pondweed (Sc) | *Potamogeton confervoides* | Nt P-Forb | 10 | M | Y |
| Curly-leaf pondweed * | *Potamogeton cripus* | Ad P-Forb | * | M | Y |
| Ribbon-leaved pondweed | *Potamogeton epihydrus* | Nt P-Forb | 8 | M | Y |
| Narrow-leaved pondweed | *Potamogeton filiformis* | Nt P-Forb | 7 | M | Y |
| Leafy pondweed | *Potamogeton foliosus* | Nt P-Forb | 4 | M | Y |
| Fries's pondweed | *Potamogeton friesii* | Nt P-Forb | 6 | M | Y |
| Pondweed | *Potamogeton gramineus* | Nt P-Forb | 5 | M | Y |
| Hill's pondweed (T) | *Potamogeton hillii* | Nt P-Forb | 9 | M | Y |
| Illinois pondweed | *Potamogeton illinoensis* | Nt P-Forb | 5 | M | Y |
| Pondweed | *Potamogeton natans* | Nt P-Forb | 5 | M | Y |
| Pondweed | *Potamogeton nodosus* | Nt P-Forb | 6 | M | Y |
| Pondweed | *Potamogeton oakesianus* | Nt P-Forb | 10 | M | Y |
| Pondweed | *Potamogeton obtusifolius* | Nt P-Forb | 10 | M | Y |
| Sago pondweed | *Potamogeton pectinatus* | Nt P-Forb | 3 | M | Y |
| Pondweed | *Potamogeton perfoliatus* | Nt P-Forb | 6 | M | Y |
| White-stemmed pondweed | *Potamogeton praelongus* | Nt P-Forb | 8 | M | Y |
| Spotted pondweed (T) | *Potamogeton pulcher* | Nt P-Forb | 10 | M | Y |
| Small pondweed | *Potamogeton pusillus* | Nt P-Forb | 4 | M | Y |
| Richardson's pondweed | *Potamogeton richardsonii* | Nt P-Forb | 5 | M | Y |
| Pondweed | *Potamogeton robbinsii* | Nt P-Forb | 10 | M | Y |
| Pondweed | *Potamogeton spirillus* | Nt P-Forb | 8 | M | Y |
| Pondweed | *Potamogeton strictifolius* | Nt P-Forb | 6 | M | Y |
| Pondweed | *Potamogeton vaginatus* | Nt P-Forb | 10 | M | Y |
| Vasey's pondweed (T) | *Potamogeton vaseyi* | Nt P-Forb | 10 | M | Y |
| Flat-stemmed pondweed | *Potamogeton zosteriformis* | Nt P-Forb | 5 | M | Y |
| Primrose Family | Primulaceae | | | D | |
| Lance-leaved loosestrife (Sc) | *Lysimachia hybrida* | Nt P-Forb | 10 | D | |
| Whorled loosestrife | *Lysimachia quadriflora* | Nt P-Forb | 10 | D | |
| Four-leaved loosestrife | *Lysimachia quadrifolia* | Nt P-Forb | 8 | D | |
| Swamp candles | *Lysimachia terrestris* | Nt P-Forb | 6 | D | Y |
| Tufted loosestrife | *Lysimachia thyrsiflora* | Nt P-Forb | 6 | D | |
| Water-pimpernel | *Samolus parviflorus (S. floribundus)* | Nt P-Forb | 5 | D | |
| Buttercup Family | Ranunculaceae | | | D | |
| Marsh marigold | *Caltha palustris* | Nt P-Forb | 6 | D | |
| Spearwort (T) | *Ranunculus ambigens* | Nt P-Forb | 10 | D | |
| Seaside crowfoot (T) | *Ranunculus cymbalaria* | Nt P-Forb | 8 | D | |
| Yellow water crowfoot | *Ranunculus flabellaris* | Nt P-Forb | 10 | D | Y |
| Lapland buttercup (T) | *Ranunculus lapponicus* | Nt P-Forb | 10 | D | |
| White water crowfoot | *Ranunculus longirostris* | Nt P-Forb | 4 | D | Y |
| Macoun's crowfoot (T) | *Ranunculus macounii* | Nt A-Forb | 10 | D | |
| Bristly crowfoot | *Ranunculus pensylvanicus* | Nt A-Forb | 6 | D | |
| Creeping buttercup | *Ranunculus reptans* | Nt P-Forb | 8 | D | Y |
| Cursed crowfoot | *Ranunculus sceleratus* | Nt A-Forb | 1 | D | Y |
| Buckthorn Family | Rhamnaceae | | | D | |
| Alder-leaved buckthorn | *Rhamnus alnifolia* | Nt Shrub | 8 | D | |
| Rose Family | Rosaceae | | | D | |
| Purple Avens | *Geum rivale* | Nt P-Forb | 7 | D | |
| Marsh cinquefoil | *Potentilla palustris* | Nt P-Forb | 7 | D | |
| Swamp rose | *Rosa palustris* | Nt Shrub | 5 | D | |
| Dwarf rasberry (En) | *Rubus acaulis* | Nt Shrub | 10 | D | |
| Spirea * | *Spiraea salicifolia* | Ad Shrub | * | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Madder Family | Rubiaceae | | | D | |
| Buttonbush | *Cephalanthus occidentalis* | Nt Shrub | 7 | D | |
| Rough bedstraw | *Galium asprellum* | Nt P-Forb | 5 | D | |
| Short-tailed bedstraw | *Galium brevipes* | Nt P-Forb | 6 | D | |
| Bog bedstraw | *Galium labradoricum* | Nt P-Forb | 8 | D | |
| Wild madder | *Galium obtusum* | Nt P-Forb | 5 | D | |
| Marsh bedstraw | *Galium palustre* | Nt P-Forb | 3 | D | |
| Stiff bedstraw | *Galium tinctorium* | Nt P-Forb | 5 | D | |
| Ditch-grass Family | Ruppiaceae | | | M | |
| Ditch grass (T) | *Ruppia maritima* | Nt P-Forb | 10 | M | Y |
| Willow Family | Salicaceae | | | D | |
| Swamp cottonwood (En) | *Populus heterophylla* | Nt Tree | 10 | D | |
| Hoary willow | *Salix candida* | Nt Shrub | 9 | D | |
| Sandbar willow | *Salix exigua (S. interior)* | Nt Shrub | 1 | D | |
| Black willow | *Salix nigra* | Nt Tree | 5 | D | |
| Bog willow | *Salix pedicellaris* | Nt Shrub | 8 | D | |
| Tea-leaved willow (T) | *Salix planifolia* | Nt Shrub | 10 | D | |
| Silky willow | *Salix sericea* | Nt Shrub | 6 | D | |
| Autumn willow | *Salix serissima* | Nt Shrub | 8 | D | |
| Salvinia Family | Salviniaceae | | | F | |
| Water fern | *Azolla caroliniana* | Nt Fern | 10 | F | Y |
| Water spangles * | *Salvinia minima* | Ad Fern | * | F | Y |
| Pitcher-plant Family | Sarraceniaceae | | | D | |
| Pitcher-plant | *Sarracenia purpurea* | Nt P-Forb | 10 | D | |
| Yellow pitcher-plant (T) | *Sarracenia purpurea f. heterophylla* | Nt P-Forb | 10 | D | |
| Lizard's-tail Family | Saururaceae | | | D | |
| Lizard's-tail | *Saururus cernuus* | Nt P-Forb | 9 | D | |
| Saxifrage Family | Saxifragaceae | | | D | |
| Golden saxifrage | *Chrysosplenium americanum* | Nt P-Forb | 6 | D | |
| Grass-of-parnassus | *Parnassia glauca* | Nt P-Forb | 8 | D | |
| Marsh grass-of-parnassus (T) | *Parnassia palustris* | Nt P-Forb | 10 | D | |
| Grass-of-parnassus | *Parnassia parviflora* | Nt P-Forb | 10 | D | |
| Swamp saxifrage | *Saxifraga pensylvanica* | Nt P-Forb | 10 | D | |
| Snapdragon Family | Scrophulariaceae | | | D | |
| Turtlehead | *Chelone glabra* | Nt P-Forb | 7 | D | |
| Red turtlehead (En) | *Chelone obliqua* | Nt P-Forb | 9 | D | |
| Golden hedge-hyssop; Goldenpert (T) | *Gratiola aurea (G. lutea)* | Nt P-Forb | 10 | D | Y |
| Clammy hedge-hyssop | *Gratiola neglecta* | Nt A-Forb | 5 | D | |
| Round-fruited hedge-hyssop (T) | *Gratiola virginiana* | Nt A-Forb | 5 | D | |
| Slender false pimpernel | *Lindernia anagallidea* | Nt A-Forb | 8 | D | |
| False pimpernel | *Lindernia dubia* | Nt A-Forb | 4 | D | |
| Winged monkey-flower (Ep) | *Mimulus alatus* | Nt P-Forb | 9 | D | |
| Jame's monkey-flower | *Mimulus glabratus var. Jamesii (M. g. fremontii)* | Nt P-Forb | 10 | D | |
| Michigan monkey-flower (En) | *Mimulus glabratus var. michiganensis* | Nt P-Forb | 10 | D | |
| Western monkey-flower (Sc) | *Mimulus guttatus* | Nt P-Forb | 8 | D | |
| Musky monkey-flower | *Mimulus moschatus* | Nt P-Forb | 10 | D | |
| Monkey-flower | *Mimulus ringens* | Nt P-Forb | 5 | D | |
| Ditch stonecrop | *Penthorum sedoides* | Nt P-Forb | 3 | D | |

Appendix 1.–Continued.

| Common name | Scientific name | PHYS | C | M/D | S/FL |
|---|---|---|---|---|---|
| Water speedwell | *Veronica anagallis-aquatica* | Nt B-Forb | 4 | D | Y |
| Brooklime * | *Veronica beccabunga* | Ad P-Forb | * | D | |
| American brooklime | *Veronica beccabunga var. americana* | Nt P-Forb | 10 | D | |
| Marsh speedwell | *Veronica scutellata* | Nt P-Forb | 6 | D | |
| Bur-reed Family | Sparganiaceae | | | M | |
| American bur-reed | *Sparganium americanum* | Nt P-Forb | 6 | M | Y |
| Bur-reed | *Sparganium androcladum* | Nt P-Forb | 6 | M | Y |
| Narrow-leaved bur-reed | *Sparganium angustifolium* | Nt P-Forb | 10 | M | Y |
| Green-fruited bur-reed | *Sparganium chlorocarpum* | Nt P-Forb | 6 | M | Y |
| Common bur-reed | *Sparganium eurycarpum* | Nt P-Forb | 5 | M | Y |
| Bur-reed | *Sparganium fluctuans* | Nt P-Forb | 10 | M | Y |
| Small bur-reed | *Sparganium minimum* | Nt P-Forb | 8 | M | Y |
| Cat-tail Family | Typhaceae | | | M | |
| Narrow-leaved cat-tail * | *Typha angustifolia* | Ad P-Forb | * | M | |
| Broad-leaved cat-tail | *Typha latifolia* | Nt P-Forb | 1 | M | |
| Hybrid cat-tail * | *Typha xglauca* | Ad P-Forb | * | M | |
| Nettle Family | Urticaceae | | | D | |
| False nettle | *Boehmeria cylindrica* | Nt P-Forb | 5 | D | |
| Valerian Family | Valerianaceae | | | D | |
| Common valerian (T) | *Valeriana ciliata* | Nt P-Forb | 10 | D | |
| Vervain Family | Verbenaceae | | | D | |
| Fog-fruit | *Phyla lanceolata* | Nt P-Forb | 6 | D | |
| Violet Family | Violaceae | | | D | |
| Marsh violet | *Viola cucullata* | Nt P-Forb | 5 | D | |
| Northern marsh violet (T) | *Viola epipsila* | Nt P-Forb | 10 | D | |
| Lance-leaved violet | *Viola lanceolata* | Nt P-Forb | 8 | D | |
| Smooth white violet | *Viola macloskeyi (V. pallens)* | Nt P-Forb | 6 | D | |
| New England blue violet (T) | *Viola novae-angliae* | Nt P-Forb | 10 | D | |
| Yellow-eyed-grass Family | Xyridaceae | | | M | |
| Yellow-eyed-grass | *Xyris difformis* | Nt P-Forb | 8 | M | |
| Yellow-eyed-grass | *Xyris montana* | Nt P-Forb | 10 | M | |
| Yellow-eyed-grass | *Xyris torta* | Nt P-Forb | 10 | M | |
| Horned Pondweed Family | Zannichelliaceae | | | M | |
| Horned pondweed | *Zannichellia palustris* | Nt P-Forb | 6 | M | Y |

[1] High values indicate plants that have high affinity for unaltered landscapes (Herman et al. 2001).
[2] Submergent and floating leaf plants listed by Voss (1972; 1985; 1996). Remaining species in this table are emergent forms or live in saturated soils.

Appendix 2.–Mollusks found in Michigan lacustrine habitats. Information compiled by Amy Harrington and Liz Hay-Chmielewski (Michigan Department of Natural Resources, Fisheries Division) from sources listed below[1]. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Clams | Unionidae | |
| Eastern elliptio | *Elliptio complanata* | Ponds with mud or gravel bottoms |
| Spike | *Elliptio dilatata* | Lakes with mud or gravel bottoms |
| Wabash pigtoe | *Fusconaia flava* | Widespread in lakes with mud, sand, or gravel substrate. |
| Plain pocketbook | *Lampsilis cardium* | Lakes with mud, sand, or gravel substrate |
| Fatmucket | *Lampsilis siliquoidea* | Ubiquitous, in lakes with all types of substrates, tolerant of moderate pollution |
| Eastern pondmussel | *Ligumia nasuta* | Found in lakes and ponds in a wide range of substrates |
| Black sandshell | *Ligumia recta* | Lakes with sand, mud, or gravel substrate |
| Threehorn wartyback | *Obliquaria reflexa* | Lakes with sand, mud, or gravel substrate |
| Pink heelsplitter | *Potamilis alatus* | Lakes with sand, mud, or gravel substrate |
| Giant floater | *Pyganodon grandis* | Quiet waters in lakes |
| Lake floater | *Pyganodon lacustris* | |
| Round lake floater | *Pyganodon subgibbosa* | Natural impoundments |
| Purple lilliput (En) | *Toxolasma lividus* | |
| Lilliput | *Toxolasma parvus* | Lakes with sandy mud, mud, or fine gravel |
| Fawnsfoot | *Truncilla donaciformis* | Lakes with sandy mud, mud, or fine gravel |
| Deer toe | *Truncilla truncata* | Lakes with sandy mud, mud, or fine gravel |
| Paper pondshell | *Utterbackia imbecillis* | Lakes and ponds |
| Rayed bean (En) | *Villosa fabalis* | Lakes, apparently associated with water willow stands (Watters 1995) |
| Fingernail and pea clams | Sphaeriidae | Swamps, ponds, creeks |
| River fingernail clam | *Sphaerium fabale* | |
| Lake fingernail clam | *Musculium lacustre* | |
| Arctic fingernail clam | *Sphaerium nitidum* | |
| Herrington fingernail clam | *Sphaerium occidentale* | |
| Swamp fingernail clam | *Musculium partumeium* | |
| Rhomboid fingernail clam | *Sphaerium rhomboideum* | |
| Pond fingernail clam | *Musculium securis* | |
| Grooved fingernail clam | *Sphaerium simile* | |
| Striated fingernail clam | *Sphaerium striatinum* | |
| Long fingernail clam | *Musculium transversum* | |
| Adam pea clam | *Pisidium adamsi* | |
| Greater European pea clam* | *Pisidium amnicum* | |
| Ubiquitous pea clam | *Pisidium casertanum* | |
| Ridgebeak pea clam | *Pisidium compressum* | |
| Alpine pea clam | *Pisidium conventus* | |
| Ornamented pea clam | *Pisidium cruciatum* | |
| Greater eastern pea clam | *Pisidium dubium* | |

Appendix 2.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| River pea clam | *Pisidium fallax* | |
| Rusty pea clam | *Pisidium ferrugineum* | |
| Giant northern pea clam | *Pisidium idahoense* | |
| Tiny pea clam | *Pisidium insigne* | |
| Lilljeborg pea clam | *Pisidium lilljeborgi* | |
| Quadrangular pea clam | *Pisidium milium* | |
| Shiny pea clam | *Pisidium nitidum* | |
| Pisidium obtusale | *Cyclocalyx obtusale* | |
| Perforated pea clam | *Pisidium punctatum* | |
| Shortended pea clam | *Pisidium subtruncatum* | |
| Triangular pea clam | *Pisidium variabile* | |
| Globular pea clam | *Pisidium ventricosum* | |
| Walker pea clam | *Pisidium walkeri* | |
| Mystery Snails | Viviparidae | |
| Ponderous campeloma | *Campeloma crassulum* | Lakes, buried in mud |
| Pointed campeloma | *Campeloma decisum* | Lakes, burrows just below surface in mud or sand |
| Chinese mysterysnail* | *Cipangopaludina chinensis malleata* | Muddy ponds and lakes |
| Japanese mysterysnail* | *Cipangopaludina japonica* | Muddy ponds and lakes |
| Banded mysterysnail* | *Viviparus georgianus* | Lakes with muddy substrate, frequently in vegetation |
| Valve Snails | Valvatidae | |
| Fringed valvata | *Valvata lewisi* | On vegetation in shallow water |
| Purplecap valvata | *Valvata perdepressa* | Large and medium-sized lakes |
| Mossy Valvata | *Valvata sincera* | Lakes with aquatic vegetation and over mud substrate |
| Threeridge valvata | *Valvata tricarinata* | Perennial lakes, in vegetation |
| Flanged Valvata | *Valvata winnebagoensis* | |
| Spire Snails | Hydrobiidae | |
| Mud amnicola | *Amnicola limosus* | Unpolluted perennial waters with aquatic vegetation, rough shores of the Great Lakes |
| Globe Siltsnail | *Birgella subglobosus* | Rare species found in large lakes, all depths, quiet water with soft silt substrate |
| Campeloma spire snail | *Cincinnatia cincinnatiensis* | Lakes, on mud or sand |
| Canadian Duskysnail | *Lyogyrus walkeri* | Perennial lakes with mud substrate and dense vegetation |
| Delta hydrobe | *Probythinella emarginata* | Perennial ales and ponds, on sand or mud substrate, in vegetation |
| Gravel Pyrg (Sp) | *Pyrgulopsis letsoni* | Recorded once under stones in a Huron River impondment |
| Boreal Marstonia | *Pyrgulopsis lustrica* | Eutrophic lakes of areas with vegetation and sand or mud substrate |
| Looping Snails | Pomatiopsidae | |
| Brown Walker (Sp) | *Pomatiopsis cincinnatiensis* | |
| Faucet Snails | Bithyniidae | |
| Mud Bithynia | *Bithynia tentaculata* | Large lakes, shallow water |
| Horn Snails | Pleuroceridae | |
| Liver Elimia | *Elimia livescens* | Lakes of all sizes, usually found on rocks and stones |
| Sharp Hornsnail | *Pleurocera acuta* | Lakes, quiet areas |

Appendix 2.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Pond Snails | Lymnaeidae | |
| Spindle lymnaea (Sp) | *Acella haldemani* | Eutrophic lakes and ponds, in reeds, depths 1-3 feet |
| Mammoth lymnaea | *Bulimnaea megasoma* | Large and small lakes, impoundments, vegeatation, usually mud substrate |
| Bugle fossaria | *Fossaria cyclostoma* | |
| Dusky fossaria | *Fossaria dalli* | Lakes, ponds, marshes, in vegetation, various substrates |
| Graceful fossaria | *Fossaria exigua* | Lakes, ponds, swamps, in vegetation, mud substrate |
| Boreal fossaria | *Fossaria galbana* | Medium to large lakes with abundant vegetation, cold, well oxygenated water |
| Rock fossaria | *Fossaria modicella* | Perennial lakes, vernal ponds, in vegetation, mud substrate |
| Golden fossaria | *Fossaria obrussa* Similar to *F. modicella* | |
| Pygmy fossaria | *Fossaria parva* | Shallow water in vegetation, lakeshores, marshes, mudflats |
| | *Fossaria peninsulae* | |
| | *Fossaria rustica* Similar to *F. modicella* | |
| Swamp lymnaea | *Lymnaea stagnalis* | Perennial water-bodies, diverse substrate, in vegetation, on rocks |
| Mimic lymnaea | *Pseudosuccinea columella* | Lakes and ponds, lily pads and reeds, shorelines |
| Big-Eared radix | *Radix auricularia* | Lakes and ponds, frequently mud substrate |
| Abbreviate pondsnail | *Stagnicola apicina* | |
| Wrinkled marshsnail | *Stagnicola caperata* | Vernal ponds, occasionally in swamps and permanent lakes |
| Woodland pondsnail | *Stagnicola catascopium* | Lakes, areas exposed to waves and currents |
| Deepwater pondsnail (T) | *Stagnicola contracta* | Live specimens found only from Higgins Lake, in *Chara* at depths of about 33 feet |
| Marsh pondsnail | *Stagnicola elodes* | Various aquatic habitats, numerous in thick vegetation on mud substrates |
| St. Lawrence pondsnail | *Stagnicola emarginata* | Open shores of lakes with gravel or stone substrate |
| Flat-whorled pondsnail | *Stagnicola exilis* | |
| Petoskey pondsnail (En) | *Stagnicola petoskeyensis* | Found only in spring brook flowing into Lake Michigan |
| Coldwater pondsnail | *Stagnicola woodruffi* | Shores of large lakes |
| Tadpole Snails | Physidae | |
| Lance aplexa | *Aplexa elongata* | |
| Glass physa | *Physa skinneri* | |
| Vernal physa | *Physa vernalis* | |
| Pumpkin physa | *Physella ancillaria* | |
| Tadpole physa | *Physella gyrina* | Perennial water-bodies, temporary swamps, pollution tolerant |
| Pewter physa | *Physella heterostropha* | Perennial water-bodies, temporary swamps, pollution tolerant |
| Ashy physa | *Physella integra* | Shallow water of lakes, all substrates |
| Broadshoulder physa | *Physella parkeri* | |

Appendix 2.–Continued.

| Common name | Scientific name | Lacustrine habitat |
| --- | --- | --- |
| Ramshorn Snails | Planorbidae | |
| Disc gyro | *Gyraulus circumstriatus* | Woodland ponds, marshes, thick vegetation, mud substrate |
| Star gyro | *Gyraulus crista* | Eutrophic ponds, dense vegetation |
| Flexed gyro | *Gyraulus deflectus* | Eutrophic waters, on vegetation with mud substrate |
| Ash gyro | *Gyraulus parvus* | Submerged vegetation in various waters with mud substrate |
| Two-ridge rams-horn | *Helisoma anceps* | Perennial lakes and ponds, in vegetation, various substrates |
| Lake Superior Rams-Horn | *Helisoma anceps royalense* | Only collected in large lakes and rivers with substrate of sand or rock, and dense vegetation |
| Bugle sprite | *Micromenetus dilatatus* | On sticks along banks in muddy bays, possibly only streams |
| Bellmouth rams-horn (Sp) | *Planorbella campanulata* | Lakes and ponds of all sizes, all substrates, usually in vegetation |
| Corpulent rams-horn | *Planorbella corpulenta* | Lakes of all sizes, often in exposed places, varying vegetation abundance and substrates |
| Acorn rams-horn (En) | *Planorbella multivolvis* | Known only from Howe Lake, Marquette County |
| (Sc) | *Planorbella smithi* | |
| Marsh rams-horn | *Planorbella trivolvis* | Lakes and ponds with mud substrate and abundant vegetation |
| Druid rams-horn | *Planorbella truncata* | Areas with wave action, various substrates |
| Thicklip rams-horn | *Planorbula armigera* | Most water-bodies, especially stagnant, with abundant vegetation |
| Sharp sprite | *Promenetus exacuous* | Various water-bodies with mud bottom, in submerged vegetation |
| Umbilicate sprite | *Promenetus umbilicatellus* | Ponds and marshes with dense vegetation and mud substrate |
| True Freshwater Limpets | Ancylidae | |
| Fragile ancylid | *Ferrissia fragilis* | Lakes and ponds, often on cattail stems |
| Oblong Ancylid | *Ferrissia parallelus* | Lakes, swamps, thick vegetation, on cattails, sedges, lily pads |
| Creeping Ancylid | *Ferrissia rivularis* | Attached to rocks and mussel shells in exposed areas of lakes |
| Cloche Ancylid | *Ferrissia walkeri* | |
| Dusky ancylid | *Laevapex fuscus* | Heavily vegetated waters, attached to vegetation |

[1] Badra and Goforth (2002); Barnhart et al. (1998); Becker (1983); Burch (1982); Burch (1991); Burch (1994); Burch and Jung (1987); Burch et al. (1991); Clarke (1981); Fuller and Brynildson (1985); Goforth et al. (2000); Goodrich and Van Der Schalie (1939); Graf (1997); Hillegass and Hove (1997); Hove (1997); Hove and Anderson (1997); Hove et al. (1997); Hove and Kurth (1998); NatureServe Explorer (2001); O'Dee and Watters (2000); Sherman (1997); Steg and Neves (1997); Turgeon et al. (1998); Van der Schale (1936); Watters (1994); Watters (1995); Watters (1996); Watters et al. (1998a); Watters et al. (1998b); and Williams et al. (1993).

Appendix 3.–Crayfish found in Michigan lacustrine habitats. Information compiled by Amy Harrington and Liz Hay-Chmielewski (Michigan Department of Natural Resources, Fisheries Division) from sources listed below[1]. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| | Cambaridae | |
| Devil crawfish | *Cambarus diogenes* | Wet meadows, marshes, spring-fed pools, ponds, artesian wells, lakes; terrestrial burrows |
| Crayfish | *Cambarus robustrus* | Stony-bottomed ponds, especially alongside streams |
| | *Fallicambarus fodiens* | Ponds, especially temporary, and marshes, burrower |
| Calico crayfish | *Orconectes immunis* | Shallow, stagnant ponds with mud bottom and abundant vegetation, burrower |
| Northern clearwater crayfish | *Orconectes propinquus* | Clear, stony ponds and lakes |
| Virile crayfish | *Orconectes virilis* | Stony lakes, deep water (9–30 feet) |
| White River crayfish | *Procambarus acutus acutus* | Most lakes, ponds, and swamps, secondary burrower |
| Rusty Crayfish* | *Orconectes rusticus* | Lakes and rivers |

[1] Crandall (2000); Creaser (1930); Crocker and Barr (1968); Hobbs (1989); and Pearse (1910).

Appendix 4.–Fish found in Michigan lacustrine habitats. Information compiled by Schneider (2002), Amy Harrington, Liz Hay-Chmielewski, and Richard O'Neal (Michigan Department of Natural Resources, Fisheries Division) from sources listed below[1]. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—Endangered, (Ep)—Extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Lampreys | Petromyzontidae | |
| Chestnut lamprey | *Ichthyomyzon castaneus* | Primarily in streams, possibly impoundments. |
| Northern brook lamprey | *Ichthyomyzon fossor* | Primarily in streams, possibly impoundments. |
| Silver lamprey | *Ichthyomyzon unicuspis* | Sand and muck in rivers as amnocetes, in lakes as adults over a variety of bottom types. |
| American brook lamprey | *Lampetra appendix* | Primarily in streams, possibly impoundments. |
| Sea lamprey* | *Petromyzon marinus* | In large lakes and Great Lakes, primarily in deep water, spawn in streams. |
| Sturgeons | Acipenseridae | |
| Lake sturgeon (T) | *Acipenser fulvescens* | Great Lakes, large inland lakes, and rivers; In shallow lakes found at all depths, in deeper lakes found at depths of 10-60 feet over soft or muck substrate. |
| Paddlefishes | Polyodontidae | |
| Paddlefish (Ep) | *Polyodon spathula* | Primarily in large rivers with slow currents, but also impoundments and associated lakes, prefers deep water with soft bottom. |
| Gars | Lepisosteidae | |
| Spotted gar (Sc) | *Lepisosteus oculatus* | Warmwater; found in small stratified and non-stratified lakes with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone at surface or mid-depths; strongly dependant on vegetation. |
| Longnose gar | *Lepisosteus osseus* | Warmwater; found in small stratified and non-stratified lakes with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone or offshore at surface or mid-depths; prefers some vegetation. |
| Bowfins | Amiidae | |
| Bowfin | *Amia calva* | Warmwater; found in lakes and reservoirs with clear to slightly turbid water; tolerant of very low dissolved oxygen; found in the littoral zone or offshore at mid-depths or on the bottom; prefers abundant or moderate vegetation. |
| Mooneyes | Hiodontidae | |
| Mooneye (T) | *Hiodon tergisus* | Large, clear rivers and their interconnecting lakes; prefers waters lower in turbidity. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
| --- | --- | --- |
| Freshwater eels | Anguillidae | |
| American eel* | *Anguilla rostrata* | Large streams and Great Lakes, nocturnal, spend the day under rocks or logs or buried in the mud with only their snouts protruding; winter burrow into soft mud and hibernate. |
| Herrings | Clupeidae | |
| Skipjack herring* | *Alosa chrysochloris* | Primarily streams, possibly in impoundments. |
| Alewife* | *Alosa pseudoharengus* | Coolwater; large and some small lakes with clear to slightly turbid water; tolerant of moderate dissolved oxygen, pelagial at mid-depths, vegetation unimportant. |
| Gizzard shad | *Dorosoma cepedianum* | Warmwater; lakes and reservoirs with turbid to clear water; tolerant of moderate or low oxygen levels, found offshore at mid-depth or at the surface; prefers sparse to moderate vegetation. |
| Carps & minnows | Cyprinidae | |
| Central stoneroller | *Campostoma anomalum pullum* | Primarily streams, possibly in impoundments. |
| Goldfish* | *Carassius auratus* | Warmwater; found in small lakes, ponds, and reservoirs with turbid to clear water; tolerant of very low dissolved oxygen; found in the littoral zone at various depths; prefers soft, silt, gravel, or sand substrate with abundant vegetation. |
| Redside dace (En) | *Clinostomus elongatus* | Primarily streams, possibly in impoundments. |
| Lake chub | *Couesius plumbeus* | Coolwater, large lakes and rivers with high dissolved oxygen; clear to slightly turbid water; in littoral zone and offshore at mid-depths or near bottom; over a variety of substrates; spawning in tributary streams with rock substrate and rocky shorelines, over a variety of substrates, acid tolerant. |
| Spotfin shiner | *Cyprinella spiloptera* | Warmwater; found in lakes and impoundments with turbid to clear water; tolerant of moderate to low dissolved oxygen; found in the littoral zone at mid-depths, surface, or bottom; prefers gravel or sand substrate and sparse to moderate vegetation; crevice spawning or on underside of submerged logs and roots. |
| Common carp* | *Cyprinus carpio* | Warmwater; found in lakes and reservoirs with turbid to clear water; tolerant of very low dissolved oxygen; found in the littoral zone or offshore on the bottom or at mid-depths; substrate- soft, gravel, sand, or silt; vegetation- moderate but variable. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
| --- | --- | --- |
| Brassy minnow | *Hybognathus hankinsoni* | Coolwater; found in bogs, ponds and small lakes; tolerant of moderate to low dissolved oxygen; clear, brown and slightly turbid water; in the littoral zone at mid-depths and bottom; substrate- gravel, sand, soft, and silt; vegetation- sparse to moderate. |
| Striped shiner | *Luxilus chrysocephalus* | Warmwater; found in small lakes and streams with clear to slightly turbid water; found in the littoral zone at mid-depths; spawning over gravel, boulder, bedrock, or sand substrate. |
| Common shiner | *Luxilus cornutus* | Warmwater; small lakes, ponds, and impoundments and small high-gradient streams, with clear to slightly turbid water; tolerant of very low dissolved oxygen; found in the littoral zone at mid-depths, surface or bottom; prefers gravel substrate, can tolerate some submerged aquatic vegetation; not very tolerant of turbidity or silted waters; spawning on gravel nests of other fish, especially those at the head of a riffle; acid intolerant. |
| Redfin shiner | *Lythrurus umbratilis* | Primarily streams, possibly in impoundments |
| Silver chub (Sc) | *Macrhybopsis storeriana* | Primarily streams, possibly in impoundments, occasionally in lakes at depths less than 30 feet. |
| Northern pearl dace | *Margariscus nachtriebi* | Coolwater, bogs and ponds, sometimes in small lakes and reservoirs; tolerant of low dissolved oxygen; in littoral zone at mid-depths; clear to slightly turbid water, vegetation sparse or unimportant; spawning—clear water, sand or gravel substrate, weak to moderate current. |
| Hornyhead chub | *Nocomis biguttatus* | Primarily streams, possibly in impoundments |
| River chub | *Nocomis micropogon* | Primarily streams, possibly in impoundments |
| Golden shiner | *Notemigonus crysoleucas* | Warmwater; lakes, ponds, and impoundments with clear to slightly turbid water; tolerant of very low dissolved oxygen; in the littoral zone at mid-depths, surface or bottom; prefers abundant or moderate vegetation; tolerant of persistent turbidity and high temperature. |
| Bigeye chub (Ep) | *Notropis amblops* | Primarily streams, possibly in impoundments |
| Pugnose shiner (Sc) | *Notropis anogenus* | Coolwater; found in small lakes with clear or brown water; tolerant of low dissolved oxygen; in the littoral zone at mid-depths; prefers moderate or abundant vegetation; intolerant of turbid or muddy waters |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Emerald shiner | *Notropis atherinoides* | Coolwater; found in large lakes and open-large stream channels with high dissolved oxygen; range of turbidities and bottom types; offshore or in littoral zone at mid-depths or surface; substrate of little importance, avoids rooted vegetation; spawning over sand or firm mud substrate or gravel shoals. |
| Silverjaw minnow | *Notropis buccatus* | Primarily streams, possibly in impoundments |
| Ghost shiner* | *Notropis buchanani* | Primarily streams, possibly in impoundments |
| Ironcolor shiner (Ep) | *Notropis chalybaeus* | Primarily streams, possibly in impoundments. |
| Bigmouth shiner | *Notropis dorsalis* | Primarily streams, possibly in impoundments, sometimes in lakes. |
| Blackchin shiner | *Notropis heterodon* | Warmwater; lakes, impoundments, and quiet pools in streams and rivers with clear or slightly turbid water; tolerant of moderate to low dissolved oxygen; found in the littoral zone at mid-depths or the surface; prefers clean sand, gravel, or organic debris substrate, and moderate or dense beds of submerged aquatic vegetation; cannot tolerate turbidity, silt, or loss of aquatic vegetation; Intolerant of lake edge modifications. |
| Blacknose shiner | *Notropis heterolepis* | Warmwater; found in clear lakes, impoundments, and pools of small, clear, low-gradient streams; tolerant of moderate to low dissolved oxygen; in the littoral zone on bottom or at mid-depths; moderate to abundant aquatic vegetation; clean sand, gravel, marl, muck, peat, or organic debris substrate; cannot tolerate much turbidity, silt, acidity, or loss of aquatic vegetation; spawning over sandy substrate; Intolerant of lake edge modifications. |
| Spottail shiner | *Notropis hudsonius* | Warmwater; found in lakes and impoundments with turbid to clear water; tolerant of moderate to low dissolved oxygen; found in the littoral zone and offshore at mid-depths; substrate- firm sand and gravel; sparse to moderate vegetation; spawning over sandy shoals or gravelly riffles, near the mouths of small streams. |
| Silver shiner (En) | *Notropis photogenis* | Primarily streams, possibly in impoundments. |
| Rosyface shiner | *Notropis rubellus* | Primarily streams, possibly in impoundments; sometimes in lakes near streams. |
| Sand shiner | *Notropis stramineus* | Warmwater; found in lakes and impoundments with clear to turbid water; in the littoral zone at mid-depths, surface, or bottom; prefers gravel or sand substrate with sparse to moderate vegetation; tolerant of some inorganic pollutants provided substrate is not covered; spawning over clean gravel or sand substrate; in winter under ice cover along shores, not tolerant of very low dissolved oxygen. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Weed shiner (Ep) | *Notropis texanus* | Lakes, sloughs, and the quiet sections of medium size streams or large rivers; substrate- sand or silt, and to a lesser extent other materials, not necessarily associated with vegetation. |
| Mimic shiner | *Notropis volucellus* | Warmwater; found in lakes and impoundments with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone at mid-depths, surface, or bottom; prefers gravel, sand, or soft substrate with moderate aquatic vegetation; aquatic vegetation necessary for spawning; acid intolerant. |
| Pugnose minnow (En) | *Opsopoeodus emiliae* | Warmwater; small lakes with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone at mid-depths or bottom; prefers soft, gravel or sand bottom with abundant vegetation; intolerant of turbidity. |
| Suckermouth minnow* | *Phenacobius mirabilis* | Primarily streams, possibly in impoundments |
| Northern redbelly dace | *Phoxinus eos* | Coolwater; found in boggy lakes and streams with slow current and clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in littoral zone or offshore at mid-depths and bottom; detritus or silt substrate and sparse or abundant vegetation; spawning-filamentous algae needed for egg deposition. |
| Southern redbelly dace (En) | *Phoxinus erythrogaster* | Primarily streams, possibly in impoundments |
| Finescale dace | *Phoxinus neogaeus* | Coolwater; found in bog lakes and streams with neutral to slightly acidic waters, infrequent in other lakes; clear or brown water; tolerant of moderate to low dissolved oxygen; in littoral zone and offshore at mid-depths and bottom; various substrates and vegetation moderate to sparse. |
| Bluntnose minnow | *Pimephales notatus* | Warmwater; found in lakes, ponds, and impoundments with clear to turbid water; tolerant of very low dissolved oxygen; in the littoral zone on bottom or at mid-depths; substrate- gravel, sand, soft, or silt; vegetation- moderate, abundant, or sparse; tolerates organic and inorganic pollutants; spawning--eggs deposited on the underside of flat stones or objects, nests in sand or gravel substrate; acid intolerant. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Fathead minnow | *Pimephales promelas* | Warmwater; found in ponds, small lakes and impoundments with brown, turbid or clear water; tolerant of very low dissolved oxygen; in the littoral zone or offshore at mid-depths or on bottom; prefers moderate to abundant vegetation; spawns on underside of objects in water 2 to 3 feet deep; prefer sand, marl, or gravel substrate; acid intolerant. |
| Longnose dace | *Rhinichthys cataractae* | Lakes and streams with high gradient, gravel, or boulder substrate; winter--quiet shallow pools, or shallow flat sand and gravel-bottomed areas. |
| Western blacknose dace | *Rhinichthys obtusus* | Primarily streams, possibly in impoundments |
| Creek chub | *Semotilus atromaculatus* | Small to medium-sized streams and rivers, rare in large rivers and lakes; clear to dark brown waters; prefers silt-free to slightly turbid waters; spawning over coarse gravel runs; winter in deeper pools and runs. |
| Loaches * | Cobitidae | |
| Oriental weatherfish* | *Misgurnus anguillicaudatus* | Quite or slow flowing waters where it burrows into muddy substrate; tolerant of very low dissolved oxygen. |
| Suckers | Catostomidae | |
| Quillback | *Carpiodes cyprinus* | Warmwater; lakes with tributary streams, and reservoirs; in shallow, clear to turbid water; substrate- sand and gravel, and to a lesser extent silt, mud, clay, and rubble. |
| Longnose sucker | *Catostomus catostomus* | In the Great Lakes and tributaries for spawning; most abundant at depths less than 37 meters and infrequent at depths greater than 55 meters. |
| White sucker | *Catostomus commersonii* | Coolwater; large and small lakes and reservoirs with clear to turbid water; tolerant of moderate dissolved oxygen; offshore or in littoral zone near bottom, substrate- gravel, sand, or soft; vegetation- moderate to sparse. |
| Western creek chubsucker (En) | *Erimyzon claviformis* | Small creeks in clear, quiet waters with thick growths of submergent vegetation and a bottom type of sand or silt mixed with organic debris; spawning in riffle areas or outlets of lakes. |
| Lake chubsucker | *Erimyzon sucetta* | Warmwater; small lakes with clear or slightly turbid water; tolerant of moderate to low dissolved oxygen; found in the littoral zone on the bottom or at mid-depths; prefers dense vegetation over bottoms of sand or silt mixed with organic debris. |
| Northern hog sucker | *Hypentelium nigricans* | Primarily streams, possibly in impoundments. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Bigmouth buffalo* | *Ictiobus cyprinellus* | Large, shallow lakes and sluggish streams; tolerant of low oxygen; substrates variable. |
| Black buffalo* | *Ictiobus niger* | Primarily streams, possibly in impoundments; variable substrates and turbidity. |
| Spotted sucker | *Minytrema melanops* | Lakes with tributary streams, and sluggish streams; turbid water; substrate- muck or sand with plant detritus, also other firm-bottomed substrates; frequents heavy vegetation. |
| Silver redhorse | *Moxostoma anisurum* | Streams, impoundments, and lakes; spawns in turbid waters in rivers. |
| River redhorse (T) | *Moxostoma carinatum* | Primarily large streams, possibly in impoundments, occasionally in lakes; intolerant of silt and pollution. |
| Black redhorse | *Moxostoma duquesnei* | Primarily streams, possibly in impoundments. |
| Golden redhorse | *Moxostoma erythrurum* | Lakes, streams, and impoundments; in the littoral zone of Lake Michigan; tolerates moderate turbidity; variable substrates. |
| Shorthead redhorse | *Moxostoma macrolepidotum* | Lakes, warm streams, and impoundments with clear to slightly turbid water; in the littoral zone of Lake Michigan; substrate- variable. |
| Greater redhorse | *Moxostoma valenciennesi* | Large lakes, possibly including the Great Lakes, medium to large rivers, and impoundments with clear water; sand, gravel, or boulder substrate. |
| Bullhead catfishes | Ictaluridae | |
| Black bullhead | *Ameiurus melas* | Warmwater; found in lakes, ponds, and reservoirs with turbid to clear water; tolerant of very low dissolved oxygen; found in the littoral zone or offshore on the bottom; prefers silt or soft substrate with moderate to abundant vegetation. |
| Yellow bullhead | *Ameiurus natalis* | Warmwater; lakes and reservoirs with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; found in the littoral zone and offshore on the bottom; prefers soft or silt substrate with abundant or moderate vegetation. |
| Brown bullhead | *Ameiurus nebulosus* | Warmwater; lakes and reservoirs with slightly turbid to clear water; tolerant of very low dissolved oxygen; found in the littoral zone or offshore on the bottom; prefers soft or silt substrate with moderate to abundant vegetation. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Channel catfish | *Ictalurus punctatus* | Warmwater; lakes and reservoirs with clear to turbid water; tolerant of moderate to low dissolved oxygen; found in the littoral zone or offshore at mid-depths or on bottom; prefers soft bottom with sparse to moderate vegetation. |
| Stonecat | *Noturus flavus* | Primarily streams, possibly in impoundments, sometimes in lakes near sand or gravel bars with wave action; spawns in lakes shallow, rocky areas of lakes under stones. |
| Tadpole madtom | *Noturus gyrinus* | Warmwater; found in small lakes; in the littoral zone or offshore on bottom; substrate- gravel, sand, or soft; vegetation- abundant to moderate. |
| Margined madtom* | *Noturus insignis* | Primarily streams, possibly in impoundments |
| Brindled madtom (Sc) | *Noturus miurus* | Primarily streams, possibly in impoundments, sometimes in lakes; spawns in lakes shores, beaches, and reefs, with eggs laid under stones. |
| Northern madtom (En) | *Noturus stigmosus* | Primarily streams, possibly in impoundments |
| Flathead catfish | *Pylodictis olivaris* | Lakes, large steams, and impoundments; tolerant of turbidity; hard or slightly silted substrate; prefers large logs and snags in rivers. |
| Pikes | Esocidae | |
| Grass pickerel | *Esox americanus vermiculatus* | Warmwater; small lakes, ponds and reservoirs with clear to slightly turbid water; tolerant of very low dissolved oxygen; found in the littoral zone at mid-depths; substrate- soft, gravel or sand; vegetation- abundant to moderate; intolerant of lake edge modification. |
| Northern pike | *Esox lucius* | Coolwater; large and small lakes and reservoirs with clear to slightly turbid water; tolerant of very low dissolved oxygen; in littoral zone and offshore at mid-depths or at surface; prefers heavy to moderate vegetation; intolerant of lake edge modification. |
| Muskellunge | *Esox masquinongy* | Coolwater; large and small lakes with clear to slightly turbid water; tolerant of low dissolved oxygen; in littoral zone and offshore at mid-depths or at surface; prefers heavy to moderate vegetation; spawning- optimum in soft, organic, nitrogen rich sediment with abundant deadwood. |
| Mudminnows | Umbridae | |
| Central mudminnow | *Umbra limi* | Warmwater; ponds, lakes and reservoirs with clear or brown water; tolerant of very low oxygen levels; in the littoral zone on bottom or mid-depths; prefer soft or silt substrate; vegetation- sparse to abundant; spawn in floodplain areas, on vegetation; acid tolerant. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Smelts* | Osmeridae | |
| Rainbow smelt* | *Osmerus mordax* | Large and small lakes with high dissolved oxygen and clear water, pelagial at mid-depths, vegetation unimportant. |
| Trouts | Salmonidae | |
| Lake herring (T) | *Coregonus artedi* | Common in large, including the Great Lakes, and small lakes with high dissolved oxygen and clear water; pelagial at mid-depths; vegetation unimportant. |
| Lake whitefish | *Coregonus clupeaformis* | Coldwater; large and small lakes with clear to slightly turbid water; tolerant of moderate dissolved oxygen; pelagial mid-depths and on bottom; substrate- rock, gravel, sand or soft; vegetation- unimportant. |
| Bloater | *Coregonus hoyi* | Primarily Great Lakes and connected waters; at depths of 20 to 170 meters. |
| Deepwater cisco (Ex) | *Coregonus johannae* | Primarily Great Lakes and connected waters; at depths of 30 to 180 meters. |
| Kiyi (Sc) | *Coregonus kiyi* | Primarily Great Lakes and connected waters; at depths of 37 to 180 meters. |
| Shortnose cisco (Ex) | *Coregonus reighardi* | Primarily Great Lakes and connected waters; at depths of 37 to 110 meters. |
| Shortjaw cisco (T) | *Coregonus zenithicus* | Primarily Great Lakes and connected waters; at depths of 20 to 160 meters. |
| Pink salmon* | *Oncorhynchus gorbuscha* | Primarily Great Lakes and connected waters, near the surface; spawning in tributary streams. |
| Coho salmon* | *Oncorhynchus kisutch* | Primarily Great Lakes and connected waters, at surface and mid-depths, spawning in tributaries. |
| Rainbow trout* | *Oncorhynchus mykiss* | Coldwater; large and small lakes and reservoirs with clear water; tolerant of moderate dissolved oxygen; offshore and the littoral zone at surface and mid-depths; vegetation unimportant; turbidity intolerant; spawn in tributaries. |
| Chinook salmon* | *Oncorhynchus tshawytscha* | Primarily Great Lakes and connected waters, at surface and mid-depths, turbidity intolerant; spawn in tributaries. |
| Pygmy whitefish | *Prosopium coulterii* | Lake Superior at depths of 18 to 90 meters. |
| Round whitefish | *Prosopium cylindraceum* | Primarily Great Lakes and connected waters, usually at depths less than 37 meters. |
| Atlantic salmon* | *Salmo salar* | Primarily Great Lakes and connected waters; turbidity intolerant. |
| Brown trout* | *Salmo trutta* | Coldwater; large and small lakes and reservoirs with clear water; tolerant of moderate dissolved oxygen; offshore and the littoral zone at all depths; vegetation unimportant; turbidity intolerant. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Brook trout | *Salvelinus fontinalis* | Coldwater; small and large lakes, ponds and reservoirs with clear or brown water; high dissolved oxygen required; turbidity intolerant; acid tolerant; vegetation unimportant; turbidity intolerant. |
| Lake trout | *Salvelinus namaycush* | Coldwater; large and small lakes with clear water and high dissolved oxygen, pelagial at mid-depths or bottom; substrate of gravel, rock, or sand; turbidity intolerant; vegetation unimportant. |
| Arctic grayling (Ep) | *Thymallus arcticus* | Primarily streams and cold lakes with extensive sand and rock substrate. |
| Trout-perches | Percopsidae | |
| Trout-perch | *Percopsis omiscomaycus* | Great Lakes and connected lakes with high dissolved oxygen, clear to slightly turbid water; substrate- clean sand or fine gravel; highly intolerant of clayey silts; avoids rooted aquatic vegetation; spawning over rocks in shallows, over sand and gravel substrates in lakes. |
| Pirate perches | Aphredoderidae | |
| Pirate perch | *Aphredoderus sayanus* | Oxbows, overflow ponds, marshes, estuaries, pools, medium to large rivers with low gradient, less than 3ft/mi; sand or muck substrates covered with organic debris, pools bordered by emergent aquatic vegetation; clear, warm, quiet water. |
| Cods | Gadidae | |
| Burbot | *Lota lota* | Coldwater; large lakes and reservoirs with high dissolved oxygen and clear water, pelagial at mid-depths or on bottom (to 90 meters); substrate- rock, gravel, sand or soft; vegetation unimportant; may use streams for spawning. |
| Killifishes | Fundulidae | |
| Western banded killifish | *Fundulus diaphanous menona* | Coolwater; quiet backwaters at the mouths of streams and lakes, prefers clear water; tolerant of moderate to low dissolved oxygen; in the littoral zone at all depths; substrate of sand, gravel, and boulders; also found over detritus substrate where patches of submerged aquatic vegetation are present; spawning in quiet areas of weedy pools; intolerant of lake edge modification. |
| Starhead topminnow (Sc) | *Fundulus dispar* | Quiet shallow backwaters with clear to slightly turbid waters and an abundance of submerged plants. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Blackstripe topminnow | *Fundulus notatus* | Warmwater; found in small lakes and impoundments with clear or slightly turbid water; tolerant of moderate to low levels of dissolved oxygen; in the littoral zone at surface or mid-depths; prefers gravel, sand, or soft substrate with moderate or abundant vegetation; spawning in vegetation or algae; winter refuge in deeper water with bottom vegetation; intolerant of lake edge modification. |
| Silversides | Atherinidae | |
| Brook silverside | *Labidesthes sicculus* | Warmwater; found in small lakes and impoundments with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone or offshore at surface or mid-depths; vegetated lakes and occasionally rivers over all types of substrates with sand being the most common. |
| Sticklebacks | Gasterosteidae | |
| Brook stickleback | *Culaea inconstans* | Inhabits a wide variety of habitats, lakes, ponds and small streams; all types of substrates in moderate to dense vegetation; tolerant of low dissolved oxygen and acidity. |
| Threespine stickleback* | *Gasterosteus aculeatus* | |
| Ninespine stickleback | *Pungitius pungitius* | Mostly along the Great Lakes shorelines to depths of 110 meters, but occasionally found in inland lakes. |
| Sculpins | Cottidae | |
| Mottled sculpin | *Cottus bairdii* | Coldwater; large and small lakes and reservoirs with high to moderate dissolved oxygen and clear water; in littoral zone and offshore on the bottom; substrate- gravel and sand; vegetation unimportant, spawning- nests under logs or rock. |
| Slimy sculpin | *Cottus cognatus* | Cold lakes; impoundments, rivers, and streams with high dissolved oxygen; gravel or rock substrate; spawning--nest in shallow areas of lakes, gravel substrate or rock ledge, |
| Spoonhead sculpin (Sc) | *Cottus ricei* | Inshore shallow and deeper waters of lakes, also shallows of large muddy rivers; usually from 20-50 meters depths in Great Lakes. |
| Deepwater sculpin | *Myoxocephalus thompsonii* | Deep, cold water lakes, most abundant at 82-91 m depth, ranging to 366 meters; spawns in deep water. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
| --- | --- | --- |
| Striped basses | Moronidae | |
| White perch* | *Morone americana* | Lakes and ponds; shallow to mid-depths, and deeper water in winter. |
| White bass | *Morone chrysops* | Lakes, impoundments, and large rivers with moderate currents, clear to turbid water; in the littoral zone; substrates- variable; spawning in the lower portions of rivers. |
| Sunfishes | Centrarchidae | |
| Rock bass | *Ambloplites rupestris* | Coolwater; large and small lakes and reservoirs with clear to slightly turbid water; tolerant of moderate dissolved oxygen; in littoral zone or offshore at mid-depths or near bottom; substrate- rock, gravel or sand; vegetation- moderate to sparse. |
| Green sunfish | *Lepomis cyanellus* | Warmwater; small lakes and reservoirs with clear to turbid water; tolerant of very low dissolved oxygen; in the littoral zone at all depths; substrate- soft, gravel, or sand; vegetation- moderate but variable. |
| Pumpkinseed | *Lepomis gibbosus* | Warmwater; lakes, ponds, and reservoirs with clear to slightly turbid water; tolerant of very low dissolved oxygen; in the littoral zone at mid-depths and on bottom; substrate- gravel, sand, or soft; vegetation- moderate to abundant; acid tolerant. |
| Warmouth | *Lepomis gulosus* | Warmwater; small lakes with clear to turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone on bottom or mid-depths; prefers soft bottom with abundant to moderate vegetation. |
| Orangespotted sunfish* | *Lepomis humilis* | Lakes, sluggish streams, and sloughs; found in turbid water with variable substrate, tolerant of silt and pollution; sparse to moderate vegetation. |
| Bluegill | *Lepomis macrochirus* | Warmwater; small and large lakes, ponds, and reservoirs with clear, brown or turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone and offshore at various depths; abundant or moderate vegetation; acid tolerant. |
| Redear sunfish* | *Lepomis microlophus* | Warmwater; lakes with clear water; in the littoral zone and offshore on the bottom; gravel, sand, or soft substrate with moderate vegetation. |
| Northern longear sunfish | *Lepomis peltastes* | Warmwater; in reservoirs and small lakes with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone at mid-depths; soft, gravel, or sand substrate; moderate to high vegetation. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Smallmouth bass | *Micropterus dolomieu* | Coolwater; large and small lakes and reservoirs with clear to slightly turbid water; tolerant of moderate dissolved oxygen; in littoral zone and offshore, near the bottom and mid-depths; rock, gravel, and sand substrate; sparse to moderate vegetation. |
| Largemouth bass | *Micropterus salmoides* | Warmwater; lakes and ponds with clear to turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone and offshore at various depths; abundant to moderate vegetation. |
| White crappie | *Pomoxis annularis* | Warmwater; in small lakes and reservoirs with slightly turbid to turbid water; tolerant of moderate to low dissolved oxygen; offshore and in the littoral zone at mid-depths; sparse to moderate vegetation. |
| Black crappie | *Pomoxis nigromaculatus* | Warmwater; in lakes and reservoirs with clear to turbid water; tolerant of moderate to low dissolved oxygen; offshore and in the littoral zone at mid-depths and at the surface; moderate to abundant vegetation. |
| Perches | Percidae | |
| Western sand darter | *Ammocrypta clara* | Primarily streams, possibly in impoundments. |
| Eastern sand darter (T) | *Ammocrypta pellucida* | Sandy bottomed areas in streams and rivers and sandy shoals in lakes |
| Greenside darter | *Etheostoma blennioides* | Primarily streams, possibly in impoundments, inhabits some relatively quite lakeshores; eggs attached to rocks, often among filamentous algae. |
| Rainbow darter | *Etheostoma caeruleum* | Primarily streams, possibly in impoundments. |
| Iowa darter | *Etheostoma exile* | Coolwater; small and large lakes, ponds, and reservoirs with clear to slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone on the bottom; gravel, sand or soft substrate; general found with submergent vegetation, especially filamentous algae that covers stones and plants. |
| Fantail darter, barred | *Etheostoma flabellare flabellare* | Primarily streams, possibly in impoundments, occasionally in lakes. |
| Fantail darter, striped | *Etheostoma f. lineolatum* | Primarily streams, possibly in impoundments, occasionally in lakes. |
| Least darter | *Etheostoma microperca* | Coolwater; small lakes with clear water; tolerant of moderate to low dissolved oxygen; in the littoral zone on bottom; gravel, sand, or soft substrate; prefers abundant vegetation. |

Appendix 4.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Johnny darter | *Etheostoma nigrum* | Coolwater; small and large lakes and reservoirs with clear, brown or slightly turbid water; tolerant of moderate to low dissolved oxygen; in the littoral zone or offshore on bottom; substrate- gravel and sand but variable; moderate but variable vegetation. |
| Orangethroat darter | *Etheostoma spectabile* | Primarily streams, possibly in impoundments. |
| Banded darter (Sc) | *Etheostoma zonale* | Primarily streams, possibly in impoundments. |
| Ruffe* | *Gymnocephalus cernuus* | Great Lakes and connected waters. |
| Yellow perch | *Perca flavescens* | Coolwater; large and small lakes, ponds, and reservoirs with clear to turbid water ; tolerant of very low dissolved oxygen; in littoral zone and offshore near bottom; gravel and sand substrate preferred but variable; moderate vegetation preferred but variable; acid tolerant. |
| Northern logperch | *Percina caprodes Semifasciata* | Coolwater; large and some small lakes with clear to slightly turbid water; tolerant of moderate dissolved oxygen; in littoral zone and offshore near bottom; sand, gravel, or rock substrate; sparse vegetation or unimportant; acid intolerant. |
| Channel darter (En) | *Percina copelandi* | Occasionally in lakes on sand and gravel beaches. |
| Blackside darter | *Percina maculate* | Primarily streams, possibly in impoundments. |
| River darter (En) | *Percina shumardi* | Primarily streams, possibly in impoundments. |
| Sauger (T) | *Sander Canadensis* | Large turbid rivers and lakes. |
| Walleye | *Sander vitreus* | Coolwater; large and small lakes and reservoirs with clear to turbid water; tolerant of moderate dissolved oxygen; in littoral zone and offshore near bottom and mid-depths; rock, gravel, sand or soft substrate; moderate to sparse vegetation. |
| Drums | Sciaenidae | |
| Freshwater drum | *Aplodinotus grunniens* | Lakes, large rivers, and impoundments with turbid to clear water; generally not in shallow, weedy areas; Great Lakes waters less than 18 meters; prefers open areas with mud substrate. |
| Gobies * | Gobiidae | |
| Round goby* | *Neogobius melanostomus* | Great Lakes and connected waters. |
| Tubenose goby* | *Proterorhinus marmoratus* | Great Lakes and connected waters. |

[1] Becker (1983); Boschung et al. (1983); Brazo and Liston (1979); Etnier and Starnes (1993); Hay-Chmielewski and Whelan (1997); Jenkins and Burkhead (1993); Kallemeyn (2000); NatureServe Explorer (2001); Scott and Crossman (1973); Trautman (1981); and Vincent (1992).

Appendix 5.–Amphibians found in Michigan lacustrine habitats. Information compiled by Amy Harrington and Liz Hay-Chmielewski (Michigan Department of Natural Resources, Fisheries Division) from sources listed below[1]. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Name | Lacustrine habitat |
|---|---|---|
| Salamanders | *Caudata* | |
| Mudpuppies and waterdogs | *Proteidae* | |
| Mudpuppy | *Necturus maculosus maculosus* | Permanent lakes including the Great Lakes |
| Sirens | *Sirenidae* | |
| Western lesser siren | *Siren intermedia nettingi* | Shallow, weedy ponds and lakes |
| Mole salamanders | Ambystomatidae | |
| Blue spotted salamander | *Ambystoma laterale* | Semi-permanent woodland ponds |
| Spotted salamander | *Ambystoma maculatum* | Woodland vernal ponds |
| Marbled salamander (T) | *Ambystoma opacum* | Woodland ponds |
| Small-mouthed salamander (En) | *Ambystoma texanum* | Woodland vernal ponds |
| Eastern tiger salamander | *Ambystoma tigrinum tigrinum* | Woodland and farm ponds, marshes |
| Newts | *Salamandridae* | |
| Red spotted newt | *Notophthalmus viridescens viridescens* | Shallow lakes, ponds, marshes |
| Central newt | *Notophthalmus viridescens louisianensis* | Shallow lakes, ponds, marshes |
| Lungless salamanders | *Plethodontidae* | |
| Four-toed salamander | *Hemidactylium scutatum* | Woodland ponds, bogs, conifer swamps |
| Frogs and toads | *Anura* | |
| True toads | *Bufonidae* | |
| Eastern American toad | *Bufo americanus americanus* | Ponds, lakes, ditches |
| Fowler's toad | *Bufo woodhousii fowleri* | Ponds in sandy open woods and fields, dunes |
| True tree frogs | *Hylidae* | |
| Blanchards cricket frog (Sp) | *Acris crepitans blanchardi* | Permanent ponds and lakes, mud flats adjacent water preferred |
| Western chorus frog | *Psuedacris triseriata triseriata* | Woodland ponds and swamps, marshes |
| Boreal chorus frog (Sp) | *Psuedacris triseriata maculate* | Woodland ponds and swamps, marshes |
| Northern spring peeper | *Psuedacris crucifer crucifer* | Ponds, marshes, swamps |
| Easter gray treefrog | *Hyla versicolor* | Lakes, ponds, swamps, marshes |
| Cope's gray treefrog | *Hyla chrysoscelis* | Lakes, ponds, swamps, marshes |
| True frogs | *Ranidae* | |
| Green frog | *Rana clamitans melanota* | Lakes and ponds with abundant vegetation & mud bottom, marshes, wooded swamps, adults stay near water. |

Appendix 5.–Continued.

| Common name | Name | Lacustrine habitat |
|---|---|---|
| Bullfrog | *Rana catesbeiana* | Permanent ponds, lakes, and marshes with mud bottom |
| Northern leopard frog | *Rana pipiens* | Marshes, meadows and gassy edges of ponds & lakes with abundant vegetation, young stay near water. |
| Pickerel frog | *Rana plaustris* | Grassy and marshy edges of lakes and bogs |
| Mink frog | *Rana septentrionalis* | Ponds, bogs and lakes with abundant vegetation |
| Wood frog | *Rana sylvatica* | Woodland ponds & bogs |

[1] Conant and Collins (1998), Harding and Holman (1992), and Ruthven et al. (1928)

Appendix 6.–Reptiles found in Michigan lacustrine habitats. Information compiled by Amy Harrington and Liz Hay-Chmielewski (Michigan Department of Natural Resources, Fisheries Division) from sources listed below[1]. Michigan status indicated as follows: *—non-indigenous, (T)—threatened, (En)—Endangered, (Ep)—Extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Turtles and tortoises | *Testudines* | |
| Snapping turtles | *Chelydridae* | |
| Snapping turtle | *Chelydra serpentine* | Marshes and muddy-bottomed lakes with abundant vegetation |
| Musk and mud turtles | *Kinosternidae* | |
| Common musk turtle | *Sternotherus odoratus* | Shallow water lakes with some vegetation; muck, marl, sand or gravel bottom |
| Pond and box turtles | *Emydidae* | |
| Spotted turtle (T) | *Clemmys guttata* | Shallow, clear water with mud bottom & abundant vegetation |
| Wood turtle (Sp) | *Clemmys insculpta* | Primarily rivers with sand sediment. |
| Eastern box turtle (Sp) | *Terrapene carolina carolina* | Use ponds for cooling in hot weather |
| Blandings turtle (Sp) | *Emydoidea blandingii* | Shallow water with mud bottom and some vegetation |
| Common map turtle | *Graptemys geographica* | Clean, large lakes |
| Painted turtle | *Chrysemys picta* | Shallow water with aquatic vegetation and mud bottom |
| Red-eared slider | *Trachemys scripta elegans* | Lakes and ponds with abundant vegetation and mud bottom |
| Softshell turtles | *Trionychidae* | |
| Spiny softshell | *Apalone [-Trionyx] spinifera* | Large lakes with sand and mud bottom |
| Lizards and snakes | *Squamata* | |
| Snakes | *Suerpentes* | |
| | *Colubridae* | |
| Kirtland's snake (En) | *Clonophis kirtlandi* | Wet meadows and forests, tamarack swamps |
| Northern copperbelly snake (En) | *Nerodia erythrogaster neglecta* | Lakes, woodland ponds, shrub wetlands |
| Northern water snake | *Nerodia sipedon sipedon* | Permanent ponds, lakes, marshes, and wetlands |
| Queen snake | *Regina septemwittata* | Edges of ponds, lakes, and marshes |
| Brown snake | *Storeria dekayi* | Areas with moist soils |
| Northern red-bellied snake | *Storeria occipitomaculata occipitomaculata* | Moist substrates including marshes and sphagnum bogs |
| Eastern garter snake | *Thamnophis sirtalis sirtalis* | Moist grassy areas near edges of ponds, lakes, and streams |
| Butler's garter snake | *Thamnophis butleri* | Moist grassy places and marshy pond and lake borders |
| Northern ribbon snake | *Thamnophis sauritus septentrionalis* | Edges of ponds, lakes, bogs, and marshes with grass, sedges, and shrubs |

Appendix 6.–Continued.

| Common name | Scientific name | Lacustrine habitat |
|---|---|---|
| Northern ringneck snake | *Diadophis punctatus edwardsi* | Moist, shady woodlands and grassy, stable dunes & beaches |
| Blue racer | *Coluber constrictor foxi* | Edges of lakes and marshes |
| Black rat snake (Sp) | *Elaphe obsoleta obsolete* | Marsh and bog edges |
| Eastern fox snake (T) | *Elaphe vulpina gloydi* | Great Lakes shoreline marshes, dunes, and beaches |
| Eastern milk snake | *Lampropeltis triangulum triangulum* | Bogs, wetlands, marshes, and lakeshores |
| Easterm smooth green snake | *Opheodrys vernalis vernalis* | Moist, grassy places |
| Vipers | *Viperidae* | |
| Eastern massasauga rattlesnake (Sp) | *Sistrurus catenatus catenatus* | Marshes and swamps |

[1] Conant and Collins (1998); Harding (1997); Harding and Holman (1990); Holman et al. (1999); and Ruthven et al. (1928).

Appendix 7.–Birds commonly associated with Michigan lake communities. These species are largely migratory and use Michigan lakes and wetlands for breeding and staging for seasonal migrations. Information compiled from sources listed below[1]. Status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern, (C)—continental concern (See Soulliere 2005).

| Common name | Scientific name | Common community type |
|---|---|---|
| Waterfowl | *Anatidae* | |
| Swans | *Cygnini* | |
| Tundra Swan(C) | *Cygnus columbianus* | Lake and marsh |
| Trumpeter swan(T, C) | *Cygnus buccinator* | Lake, marsh, and river |
| Mute Swan* | *Cygnus olor* | Lake, marsh, and river |
| Geese | *Anserini* | |
| Canada goose | *Branta canadensis* | Lake, marsh, river, and swamp |
| Ducks | *Anatinae* | |
| Wood duck | *Aix sponsa* | River, stream, swamp, and marsh |
| Green-winged teal | *Anas crecca* | Marsh and swamp |
| American black duck(C) | *Anas rubripes* | Marsh, river, and swamp |
| Mallard | *Anas platyrhynchos* | Marsh, river, and swamp |
| Northern pintail(C) | *Anas acuta* | Marsh |
| Blue-winged teal(C) | *Anas discors* | Marsh |
| Northern shoveler | *Anas clypeata* | Marsh |
| Gadwall | *Anas strepera* | Marsh |
| American wigeon | Anas americana | Marsh and lake |
| Canvasback(C) | *Aythya valisineria* | Lake and marsh |
| Redhead(C) | *Aythya Americana* | Lake and marsh |
| Ring-necked duck | *Aythya collaris* | Marsh and lake |
| Greater scaup | *Aythya marila* | Lake |
| Lesser scaup(C) | *Aythya affinis* | Lake |
| Long-tailed duck | *Clangula hyemalis* | Lake |
| Common goldeneye(C) | *Bucephala clangula* | Lake, river and swamp |
| Bufflehead | *Bucephala albeola* | Lake and river |
| Hooded merganser | *Mergus cucullatus* | River, stream, marsh, and lake |
| Common merganser | *Mergus merganser* | Lake and river |
| Red-breasted merganser | *Mergus serrator* | Lake and river |
| Ruddy duck | *Oxyura jamaicensis* | Lake and marsh |
| Waterbirds | | |
| Grebes | *Podicipedidae* | |
| Horned grebe | *Podiceps auritus* | Lake and marsh |
| Pied-billed grebe | *Podilymbus podiceps* | Lake and marsh |
| Rails, Moorhens, and Coots | *Rallidae* | |
| King rail(E, C) | *Rallus elegans* | Marsh |
| Virginia rail | *Rallus limicola* | Marsh |
| Sora | *Porzana Carolina* | Marsh |
| Common moorhen (Sc) | *Gallinula chloropus* | Marsh |
| American coot | *Fulica americana* | Marsh and lake |

Appendix 7.–Continued.

| Common name | Scientific name | Common community type |
|---|---|---|
| Wading birds | | |
| Herons | *Ardeidae* | |
| American bittern(Sc, C) | *Botaurus lentiginosus* | Marsh |
| Least bittern(T, C) | *Ixobrychus exilis* | Marsh |
| Great blue heron | *Ardea herodias* | Marsh, river, stream, and swamp |
| Great egret | *Casmerodius albus* | Marsh |
| Cattle egret | *Bubulcus ibis* | Marsh |
| Green-backed heron | *Butorides striatus* | Marsh and swamp |
| Black-crowned night-heron(C) | *Nyticorax nyticorax* | Marsh and swamp |
| Gulls and terns | *Laridae and Sterinae* | |
| Bonaparte's gull | *Larus Philadelphia* | Lake |
| Ring-billed gull | *Larus delawarensis* | Lake |
| Glaucous gull | *Larus hyperboreus* | Lake |
| Herring gull | *Larus argentatus* | Lake |
| Little gull | *Larus minutus* | Lake |
| Great black-backed gull | *Larus marinus* | Lake |
| Iceland gull | *Larus glaucoides* | Lake |
| Caspian tern (T) | *Sterna caspia* | Lake |
| Common tern(T, C) | *Sterna hirundo* | Lake |
| Forster's tern(Sc, C) | *Sterna forsteri* | Lake |
| Black tern(Sc, C) | *Chlidonias niger* | Marsh and lake |
| Shorebirds | | |
| Plovers and Sandpipers | *Charadriidae and Scolopacidae* | |
| Piping plover(E, C) | *Charadrius melodus* | Lakeshore |
| Greater yellowlegs(C) | *Tringa melanocleuca* | Marsh |
| Lesser yellowlegs | *Tringa flavipes* | Marsh |
| Spotted sandpiper | *Actitus macularia* | Lake and river shoreline |
| Solitary sandpiper(C) | *Bartramia longicauda* | Lake and river shoreline |
| Dunlin | *Calidris alpina* | Lakeshore |
| Long-billed dowitcher | *Limnodromus scolopaceus* | Marsh |
| Ruddy turnstone(C) | *Arenaria interpres* | Lakeshore |
| American woodcock(C) | *Scolopax ;minor* | Lowland forest and swamp edge |
| Common snipe | *Gallinago gallinago* | Marsh and lakeshore |
| Raptors | | |
| Osprey (T) | *Pandion haliaetus* | Lake and river |
| Bald eagle (T) | *Haliaeetus leucocephalus* | Lake and river |
| Northern harrier (Sc) | *Circus cyaneus* | Marsh |
| Sharp-shinned hawk | *Accipiter striatus* | Lowland forest edge |
| Cooper's hawk | *Accipiter cooperil* | Lowland forest edge |
| Red-tailed hawk | *Buteo jamaicensis* | Lowland forest |
| Rough-legged hawk | *Buteo lagopus* | Lowland forest |
| Broad-winged hawk | *Buteo platypterus* | Lowland forest |
| American kestrel | *Falco sparverius* | Lowland forest and swamp edge |
| Short-eared owl (E) | *Asio flammeus* | Marsh |

Appendix 7.–Continued.

| Common name | Scientific name | Common community type |
|---|---|---|
| Perching and other birds | *Passeriformes* | |
| Belted kingfisher | *Ceryle alcyon* | River and stream |
| Marsh wren (Sc) | *Cistothorus palustris* | Marsh |
| Sedge wren | *Cistothorus platensis* | Marsh edge |
| Veery | *Catharus fuscescens* | Lowland forest |
| Yellow warbler | *Dendroica petechia* | Lowland forest edge |
| Common yellowthroat | *Geothlypis trichas* | Marsh, river and lake edge |
| Eastern meadowlark | *Sturnella magna* | Marsh and river edge |
| Yellow-headed blackbird (Sc) | Xanthocephalus xanthocephalus | Marsh |
| Red-winged blackbird | *Agelaius phoeniceus* | Marsh |
| Common grackle | *Quiscalus guiscula* | Marsh and forest edge |
| Swamp sparrow | *Melospiza Georgiana* | Marsh |
| Savannah sparrow | *Passerculus sandwichensis* | Marsh edge |

[1] Brewer et al. (1991); Brown et al. (2001); Helmers (1992); Hendendorf et al. (1986); Kushlan et al. (2002); Monfils (1996); NAWMP (2004); and Soulliere (2005).

Appendix 8.–Mammals commonly associated with Michigan lake communities. Data compiled from sources listed below[1]. Status indicated as follows: *—non-indigenous, (T)—threatened, (En)—endangered, (Ep)—extirpated, (Ex)—extinct, (Sc)—special concern.

| Common name | Scientific name |
|---|---|
| Virginia opossum | *Didelphis virginiana* |
| Eastern cottontail | *Sylvilagus floridanus* |
| European hare | *Lepus capensis* |
| Woodchuck | *Marmota monax* |
| Gray squirrel | *Sciurus carolinensis* |
| Fox squirrel | *Sciurus niger* |
| Red squirrel | *Tamiasciurus hudsonicus* |
| Muskrat | *Ondatra zibethicus* |
| Red fox | *Vulpes fulva* |
| Raccoon | *Procyon lotor* |
| Long-tailed weasel | *Mustela frenata* |
| Mink | *Mustela vison* |
| Striped skunk | *Mephitis mephitis* |
| Badger | *Taxidea tus* |
| White-tailed deer | *Odocoileus virginianus* |
| Otter | *Lutra Canadensis* |
| Water shrew | *Sorex palustris* |
| Star-nosed mole | *Condylura cristata* |
| Beaver | *Castor canadensis* |

[1] Baker 1983.

Appendix 9.–Lake watershed assessments and management plans.

# LAKE WATERSHED ASSESSMENTS AND MANAGEMENT PLANS

The natural resources of Michigan lakes are used by a multitude of recreational and commercial stakeholders. Swimming, boating, sunbathing, relaxation, scuba diving, sightseeing, fishing, hunting, trapping, and wildlife viewing are some of the reasons people are attracted to lakes. In 2001, the value of fishing, migratory bird hunting, and wildlife viewing on Michigan lakes was estimated at over $1 billion. Many lakes are heavily developed for varying human interests by riparian property owners. Recreational use, commercial use, and residential development continue to increase on and along the shores of our lakes.

Roughly 40% of Michigan is covered by the Great Lakes and 1,000 square miles is covered by inland lakes. There are over 35,000 mapped inland lakes with a surface area 0.1 acres or larger. Over 2,000 are larger than 50 acres and 11,000 are larger than 5 acres. Houghton Lake is the largest inland lake in Michigan encompassing 20,044 acres.

Lakes are some of the most productive and biologically diverse ecosystems in Michigan. Under the public trust doctrine, Michigan holds natural resources in trust for the benefit of the people of Michigan. The views of diverse stakeholders on management of natural resources in lakes can be very different. A thorough knowledge and proper planning of lake resources and human alterations will help assure ecosystem integrity and sustainable natural resources for current and future generations of Michigan citizens.

Lake assessments and management plans provide an organized approach to identifying opportunities and solving problems. They provide a mechanism for public involvement in management decisions; allowing citizens to learn, participate, and help determine decisions. These documents provide an organized reference for Department of Natural Resources personnel, other agencies, and citizens who need information about a particular aspect of a lake system.

Inland lakes can have relatively small to very large watersheds, depending on the number and size of their tributary streams. Lakes with no tributary streams will have relatively small watersheds. Some lakes have very large tributary streams encompassing some of the largest watersheds in Michigan. Depending on the size of the watershed and available resources, river assessments and plans may be developed separately from lake assessments and plans.

The process of developing an assessment and management plan is provided below. The procedures are intended for Department of Natural Resources use, but can serve as a guide for other organizations involved in lake planning. The assessment incorporates a review of the physical, biological, and social features of the lake’s watershed. A list of management options are developed based on assessment of the watersheds features. A draft of the assessment is then distributed to the public and interested groups and agencies. Appropriate revisions are made to the assessment following public comment, and options are selected and incorporated into a management plan.

Required and recommended information and procedures for assessments will change as new research and techniques become available. Detailed directions for developing assessments will not be provided here. A current description of features and information that should be incorporated into lake assessments is provided below. Lake assessments will have standard formats including the following preliminary sections: Cover Page, Title Page, Table of Contents, List of Tables, List of Figures, List of Appendices, Acknowledgements, and Executive Summary.

Appendix 9.–Continued.

# INTRODUCTION

The introduction should describe the purpose and goals of the lake assessment and management plan. A summary of the process used to complete these documents should be incorporated. All stakeholders and partners involved in development of the documents should be listed.

# ASSESSMENT

The assessment provides a description of the historical and present day natural resources in the lake. It summarizes the physical, biological, and social factors that have influenced resources historically, and will influence future management. The assessment provides the framework and boundaries that guide management direction. A description of the various features that should be incorporated into the assessment follows.

## Geography

Information in this section should provide a description of the location of the waterbody and watershed in Michigan, tributary streams, watershed size, river basin, and Great Lakes basin. Political boundaries such as counties, cities, villages, and other landmarks should be described. The Michigan Department of Natural Resources (DNR), Digital Water Atlas of Michigan and the Michigan Geographic Data Library can provide much of the information.

## History

Provide a brief overview of human modifications and present day uses of the lake and its watershed. Typical topics that should be included are human population abundance, historical vegetation and logging activities; agricultural, commercial, industrial, and residential development; chemical and nutrient pollution; major alterations to the lake bottom, shoreline, and biological communities; and changes of important resources. Natural resources agency reports and local libraries are sources of information.

## Basin Geology, Soils, and Hydrology

The geology and soils of the basin determine much of the hydrology. This description should focus on surface geology because it primarily affects the hydrology and water quality of lakes. Discuss surface geology types and determine the amount of each type in the watershed, along with soil types (e.g., outwash, moraines, till, bedrock, sands, clays loams, etc.). Information is available from the Quaternary Geology of Michigan, surface geology map of Michigan, Natural Rivers Reports if available, Michigan Department of Environmental Quality (DEQ) MIRIS database, and U. S. Department of Agriculture (USDA) Natural Resources Conservation Districts.

Summarize groundwater and surface water inflows and outflows. Determine a water budget and residence time for the lake if possible. Inflows for the water budget include groundwater, tributaries, other surface runoff and discharges, and direct rainfall. Outflows include groundwater, streams, evaporation, and withdrawals. The sources described below can help determine the water budget. The

Appendix 9.–Continued.

evaluation of discharge from tributary streams can be useful in determining if development and drainage in the watershed is affecting water quality.

### *i) Climate*

Climate includes rainfall and temperatures in the basin. Data can be obtained from US weather service site locations and either Eichenlaub's (1990) or Sommer's (1977) climatic atlas. Determine average amount of rainfall and seasonal patterns. Calculate water yield (cfs) per square mile of the watershed. Discuss evaporation, winter severity, and growing season.

### *ii) Annual Stream Flows*

Describe average annual flows and annual patterns of discharge from streams entering and leaving the lake. Generally this information is available only from USGS gauge sites (data available on the web at http://www.usgs.gov). If gauge information is not available, models may provide relevant information. For each location calculate average yield (average annual discharge/drainage area). This gives a broad sense of the water budget for the watershed. Used with precipitation data, you can calculate how much water is lost to evapotranspiration before it gets to the stream. This is particularly important in forested watersheds. Consider flow regulations if dams are present, and water withdrawals for irrigation and industrial use.

### *iii) Seasonal Stream Flows*

Seasonal flows help determine flow stability in streams. Flow duration curves, with the data in 5% intervals (USGS web site) will be needed. Develop graphs with percent exceedence on the x axis and standardized discharge on the y axis. For low flow data, the higher the standardized discharge number, the more stable the system is. This is due to groundwater influxes that continually provide water to the stream even during dry periods. For high flow data, the lower the standardized discharge number, the more stable the system is. Stability of stream discharge during rainfall and snowmelt periods results because water infiltrates into the soils and is released slowly, rather than quickly flowing over the surface of the ground to the stream. These values can be compared to other Michigan streams to determine groundwater/surfacewater relationships. Using discharge information and information from the Michigan Valley Segment Ecological Classification System (VSEC), inferences can be made on potential changes in surface runoff in the watershed.

### *iv) Daily Stream Flows*

In natural systems daily flow changes are generally gradual. However, impoundments from dams or lake-level control structures can cause dramatic changes in short periods of time. Look at mean daily discharge data for all gauge locations; determine if any unusually wide day to day variation occurred.

Appendix 9.–Continued.

*v.) Dams and Barriers*

Dams and barriers in tributary streams should be considered in any flow evaluation. They also have effects on animal movements. Lake-level control dams also affect lake water levels and habitat features of the lake.

*vi.) Great Lakes Influences*

Great Lakes water levels and influxes need to be considered where they influence the lake.

Sources of information include the Michigan Geographic Data Library (VSEC), Michigan USGS Water Resources Division (mi.water.usgs.gov/), DEQ Geological Survey Division, Michigan State University Institute of Water Research, and university libraries.

## Land Use

Land use within the watershed and along the shoreline of a lake affects the hydrology of the system and the level of nutrients, chemicals, dissolved substances, and bedload sediment discharged into the lake. Land use along the shoreline of the lake affects water quality, biological communities, and various habitat components like aquatic and land vegetation, deadwood, and shoreline slope.

Describe the historical and present landscape of the watershed. Note any unique areas and why. Discuss and quantify major land-use categories such as agriculture, forest, and urban uses including impervious surface area. Include artificial drainage including designated drains and road drains. Review other relevant alterations like bridge crossings, culverts, roads, oil and gas pipelines, and utility crossings.

Shoreline areas of the lake can be treated separately in the discussion. Include evaluation of these components:

- Tree densities (> 2” in diameter) within 30 feet of the shoreline.
- Shoreline length and lengths of shoreline in the following categories: natural shoreline, semi-natural shoreline (e.g., lawn with emergent vegetation), vertical or hard seawall, rock rip-rap seawall, developed or artificial (lawns, beaches), total number of residences
- Locations of all shallow and deep water wells along the shoreline.
- Density (number/mi) of homes and cottages along the shoreline.

Information sources include the Michigan Geographic Data Library, USDA Natural Resources Conservation Districts, DEQ MIRIS Database, local Health Departments and lake associations, and universities.

## Lake Morphology

The three dimensional shape of a lake influences water temperature, dissolved oxygen levels, aquatic plant growth, overall biological production and trophic status, biological communities and development. Parameters that should be evaluated include:

Appendix 9.–Continued.

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- Surface area, volume, maximum length, mean width, maximum width, mean depth, maximum depth, shoreline length, natural shoreline development, and slope of the bottom.
- Total surface area of littoral zone and plant coverage of total lake surface area.
- Bottom depth contours (5 ft.)—include volume of water within each depth contour.
- Wetlands, dunes, or other special features that may be located adjacent the shoreline
- Quantify and discuss all historical dredging and filling (including beach sanding) within the lake and adjacent wetlands.

Information sources include the DNR Digital Water Atlas of Michigan and the Michigan Geographic Data Library, and DEQ P.A 203 (Wetland Protection) and 346 (Inland Lakes and Streams) permits.

## Water Quality

Water quality is a habitat component that influences the types and levels of biological communities. Water temperatures, oxygen, and pH levels influence animal communities; alkalinity influences production; chlorophyll-a, transparency, and nutrient concentrations help determine trophic state; sediment cores help determine historical changes in trophic state; and chemical analyses of water and sediment is needed to determine if pollution is present. Water quality parameters that are important to evaluate include:

Water temperatures—includes temperature profiles of the entire water column to determine epilimnion, metalimnion, and hypolimnion layers.

Dissolved oxygen—collected in the epilimnion; upper, middle, and lower metalimnion; and upper and lower hypolimnion.

- Alkalinity and pH.
- Nitrogen and phosphorus in the water column, preferably during spring and fall turnover periods.
- Chlorophyll-*a* concentrations.
- Transparency, using a secchi disc.
- Sediment coring and nutrient history.

Generally, organic and metal contaminants are not a significant problem in inland waters unless there have been historic discharges to a lake. Airborne contaminants can sometimes be a problem for inland waters, especially for mercury. The Great Lakes and some of the larger connected inland waters and bays have significant historical contamination and some level of ongoing contaminant inputs from industrial discharges, upland runoff carried from tributary streams and stormwater discharges, and airborne sources. Other sources of contamination may include historical land contamination sites that have polluted groundwater. Fish contaminants are a human health issue but advisories often indicate pollution problems and should be summarized.

Sources of information include DEQ Surface Water Quality Division, DNR lake survey records, and the Michigan Department of Public Health for fish contaminant advisories.

Note- for non-point source grants through DEQ, management plans must be developed using specific processes. Refer to Brown et al. (2000) or www.michigan.gov/deq.

Appendix 9.–Continued.

## Biological Communities

The biological communities represent a significant portion of the natural resources of our lakes and are widely used for recreation, food, and commercial enterprises. Species composition and abundance is often a good measure of ecosystem health, especially when compared to original conditions or Michigan lakes with similar characteristics. Discussion should incorporate physical and social factors to explain biological communities and changes that have occurred from original conditions.

Describe the biological community including phytoplankton, submergent plants, emergent plants, and near-shore upland plants; invertebrates including microcrustaceans, insects, crayfish, and mussels; fish; amphibians; reptiles; birds; and mammals. Birds and mammals discussed should be those that require the lake for survival. Include summaries of non-indigenous species, extinct species, and the status of species low in abundance or extirpated. Provide a general overview of habitat features as related to the biological community. Include special communities, such as, bogs, swamps, marshes, and wetlands. Summarize resource changes and factors that have affected the biological community since European settlement, like deforestation, development, pollution, changes in water quality and trophic status, lake-level dams, land use, aquatic vegetation removal programs, dredging and filling, seawalls, shoreline development, fish stocking, and harvest of resources. Discuss where important information is lacking or limited.

Aquatic plant summaries should include total coverage of lake surface area, species composition, and relative coverage and densities of dominant plants. Note- for Aquatic Nuisance Control permits, DEQ approved plant sampling procedures must be used for plant community descriptions. Evaluate wetland plant communities using the Floristic Quality Assessment (Herman et al. 2001). Evaluate habitat quality using fish community indices from Schneider (2002) and Schneider (1990).

Information sources include DNR and DEQ records and reports, universities, and libraries.

## Resource Management

The Department of Natural Resources is responsible for managing the natural resources of the state, and for the protection of the public trusts in these resources. Discuss historical and present resource management practices for forestry, animals, and water quality. These can include activities within the watershed when relevant. Discuss regulations, user preferences, harvest, and pressure. Identify high-use resources. Summarize research and studies. Identify potential goals for the future.

Other agencies and groups may have plans related to, or affecting natural resources. A summary of relevant features of these plans should be included in the discussion.

## Recreation Use

Michigan lakes are used for a multitude of recreational uses. Recreation sometimes directly uses the animal communities. Other uses often have indirect effects on the resources that may be in conflict with good resource management.

Summarize recreation activities like fishing, hunting, trapping, boating, wind surfing, swimming, wildlife observation, hiking, nature study, and picnicking. Include public lands and access sites. Discuss any relevant conflicts.

Appendix 9.–Continued.

Sources of information include DNR records and reports, and the U. S. Fish and Wildlife Service, National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

### Special Jurisdictions

Generally there are several to many entities that have legal jurisdiction over a lake. These jurisdictions may affect resources or resource management.

Summarize federal, state, and local laws that affect the watershed. Determine if the water has been adjudicated navigable under federal or state law. Jurisdictions may include county drain commissioners, natural rivers designations, state game areas, state parks, refuges, and county or city parks. Determine the existence of an established legal lake-level, a lake board, or a special assessment district under P. A. 451. Local zoning laws should be described, especially relative to water frontage properties. Local wastewater and storm water management systems should be included.

Information sources include the DEQ website (http://www.michigan.gov/deq) for state laws, DNR Guide to Public Rights on Michigan Waters (Law Enforcement Division Report Number 9, 1993), and federal and local government offices.

### Citizen Involvement

Natural resources are managed to provide optimum benefits for the citizens of the state by the Department of Natural Resources. Active citizen involvement in management activities can vary greatly.

Summarize interested groups and partners involved in lake activities including watershed councils, government entities, hunting and fishing groups, and environmental organizations. Discuss relevant activities of these groups to resource management.

## MANAGEMENT OPTIONS

A list of management options is prepared based on the assessment of resources in the lake and its watershed. Generally, these options are designed to protect, restore, rehabilitate, mitigate, or enhance natural resources in the system. It is advantageous to describe options in this manner because it helps selection of management options for the management plan. For example, protection activities are usually superior to enhancement activities.

Options must be consistent with the mission statement of the Department of Natural Resources. This mission is to protect and enhance the public trust in natural resources, and promote optimum use of these resources. Options must follow the eight guiding principals of ecosystem management described earlier in this document.

Appendix 9.–Continued.

## PUBLIC COMMENT AND REVIEW

A draft of the assessment will be distributed for public comment. All provided comments will be listed and discussed, with any changes to the assessment noted.

## GLOSSARY

Describe any technical or biological terms used in the document.

## REFERENCES

List references cited in the format specified for the North American Journal of Fisheries Management.

## MANAGEMENT PLAN

A lake management plan is developed following completion of the assessment. The management plan consists of a series of management actions based on selected management options from the assessment. Each management action includes a summary of the management options upon which it is based, the reason for selection, whether it is a long-term or short-term objective, and for short-term objectives a schedule for implementation that includes a time frame, personnel needed, special needs, and finances required.