Wisconsin's Biodiversity as a Management Issue

A REPORT TO DEPARTMENT OF NATURAL RESOURCES MANAGERS

MAY 1995

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Department of Natural Resources
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This report was written for Department of Natural Resources managers to provide them with a context for their work. The Natural Resources Board met on April 27, 1995 to review the report. At this meeting, the Board accepted the Department's recommendations, as follows:

- Print and distribute the report "Wisconsin's Biodiversity as a Management Issue," and use it to continue an open dialogue with the Department's partners and customers;
- Adopt the four strategic recommendations in the revised report (as summarized on pages 7-8 and described on pages 37-39), and use them to guide policy development; and
- Further analyze the implications of the "possible actions" listed for the seven biological community types in the report. The Department will work with the Board to determine the most appropriate sequence for these analyses and to set priorities for using them to develop policy.

In moving to approve the report, the Board also stated that its approval "is made with the understanding that the Natural Resources Board does not endorse, recommend, or sanction the use of this report to judge whether or not a management or regulatory act is appropriate or inappropriate."

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CHAPTER 1

Executive Summary

Purpose of this Report

This report presents a Department strategy for the conservation of biological diversity. It provides Department of Natural Resources (DNR) employees with an overview of the issues associated with biodiversity and provides a common point of reference for incorporating the conservation of biodiversity into our management framework. It will be used as a discussion piece for dialogue with the public and will be useful for Natural Resources Board members as they include attention to biodiversity in the development of public policy.

Our goal is sustainable ecosystems. These ecosystems, whether highly modified by humans or largely natural, exhibit ecological characteristics that maintain biological diversity across all land uses. To reach this goal we must develop management solutions that blend people's needs with nature's capacity to sustain those needs over the long term. These management solutions must be founded in the perspective that humans are part of, not apart from, the global ecosystem. Like all species, we depend on a viable biosphere. But unlike other species, we have it in our power to destroy the ecosystems on which we depend. Today's decisions will have far-reaching impacts on the choices and quality of life available to us in the future.

This report provides a historical perspective on natural resources management, reviews the range of public values relating to biodiversity, and explores DNR's role in managing natural resources to conserve biodiversity. It presents ecosystem management as the framework that will help us balance human needs and values with the conservation of biological diversity, and it proposes approaches and tools to help the Department and its partners move more fully into ecosystem management. The report also offers an overview of the state's seven major biological communities, describing each, documenting changes that have occurred since the early 1800s, outlining current issues, and suggesting possible actions.

What is Biodiversity?

Biodiversity is a shortened form of the term "biological diversity." Simply stated, it is the entire spectrum of life forms and the many ecological processes that support them. Biodiversity occurs at four interacting levels: genetic diversity, species diversity, community diversity, and ecosystem diversity. Genetic diversity is the spectrum of genetic material carried by all the individuals of a particular species. Species diversity is the variety of species in a geographic area, including not only the number of species but also their relative abundance and spatial distribution.

A community is an assemblage of different plant and animal species, living together in a particular area, at a particular time, in specific habitats. Communities usually are named for their dominant plant species (for example, pine barrens, sedge meadows, and oak savannas). Communities range in size from less than an acre to thousands of acres. Communities are always changing, though often they change too slowly for humans to notice in our brief lifetimes.

An ecosystem includes not only biological communities but also the myriad, continuing interactions of biological communities with their abiotic (nonliving) environment, including moisture, temperature, sunlight, soil, and many other physical and chemical factors. Ecosystems, which range in size from minute to millions of acres, exhibit complex linkages among plants, animals and the physical and chemical environments. Ecosystem diversity is largely determined by the amount and complexity of these linkages. Ecosystems, like biological communities, are in a constant state of change, called "ecological succession." Succession is the progressive change through time of species composition, organic structure, and energy flows throughout an ecosystem. Human activities and natural phenomena such as fire and tornados can alter succession.

Wisconsin is blessed with abundant biodiversity. Located at the junction of three of North America's six biotic provinces—the eastern deciduous forest, the northern boreal forest, and the temperate grasslands—we have a wealth of species and natural communities. Approximately 1,800 species of native plants and 657 species of native vertebrates have been identified in Wisconsin. In addition, there are thousands of species of nonvascular plants and invertebrates. The challenge is to manage this diversity to conserve Wisconsin's biological heritage and preserve future management options.

Ecological Issues

When the glaciers receded from this part of the continent 10,000-12,000 years ago, humans moved into the area along with colonizing plants and animals. Native Americans managed the landscape using fire, agriculture, and harvest of plants and animals. They undoubtedly affected large portions of the Wisconsin landscape. When European and American settlers moved into Wisconsin in the early 1800s, the state's landscape was characterized by extensive forests, grasslands, wetlands, and a variety of other large communities. Fire, often purposefully set by Native Americans, was a major factor in maintaining many of these communities, especially grasslands, savannas, and barrens. Euro-American settlement brought many changes to this landscape, including suppression of fire, large-scale intensive agriculture, and urban and industrial development. Today, Wisconsin's landscape is a mosaic of urban areas, farms, commercial and recreational forests, lakes and wetlands, and a small amount of land in protected natural areas. All the natural communities present in the early 1800s have been significantly altered in function or size, with some existing today only as remnant areas.

Managing Wisconsin's natural resources in the context of biodiversity requires that we understand the combination of forces that produced today's landscape and the effect of human activities on biological communities and ecosystems. Although these forces are complex, it is important that we understand them, support patterns of resource use consistent with our goal of sustainable ecosystems, and accept responsibility for the problems raised by intensive human use of the landscape. These problems can be grouped into three major categories for discussion: **ecological simplification**, **fragmentation**, and **environmental pollution**.

Ecological simplification means that the interrelationships between organisms and their environments are reduced in number and complexity. Every organism in an ecosystem has one or more roles to play in sustaining that ecosystem. For example, bacteria and fungi cause dead trees to rot, providing nutrients for plants, which in turn provide food for birds and small mammals, which are then eaten by predators. If these natural processes are interrupted, ecological simplification can occur. Simplification is caused by loss of habitat, loss of species in a community, and air and water pollution that affects chemical and physical processes. The addition of non-native species can also simplify biological communities and ecosystems, disrupting the food chain, destroying habitat for native species, displacing native species, and otherwise upsetting natural processes. Ecological simplification can also result from land management practices that reduce natural variety on the landscape, such as filling wetlands or planting only one species of tree. The effects of simplification are often complicated and subtle, reducing the number of species in an area, and the genetic variety among individuals of a species.

Fragmentation is the breaking up of large and continuous ecosystems and communities into smaller areas surrounded by altered or disturbed areas. Modern civilization has greatly fragmented the landscape. Farms have been created in the middle of forests, and prairies have been plowed for agriculture. Wetlands have been filled. Rivers and streams have been dammed, interrupting corridors used for animal movement and isolating populations and habitats. Some species, such as white-tailed deer, do well in these altered landscapes. However, many species of plants and animals have declined in number as habitats have become too small to allow successful reproduction and isolated populations have lost genetic diversity.

Environmental pollution is the human-induced addition of many types of substances to air, land, and water in quantities or at rates that harm organisms, habitats, communities, ecosystems, or human health. Water pollution destroys aquatic habitats and kills aquatic life through toxicity, by destroying habitat, or by using up dissolved oxygen. Acid rain and air-borne contaminants such as heavy metals and pesticides affect both aquatic and terrestrial plants and animals.

Despite the problems caused by ecological simplification and fragmentation, both can be consistent with management objectives. Enhancing populations of certain plant and animal species, providing forest and agricultural products, and accommodating other human activities are obviously important and necessary. The key is to take a landscape-scale view, seeing the overall mosaic of land and water use in Wisconsin; to recognize the impacts of our proposed actions; to clarify where, when, and why these actions are desirable; to know the trade-offs; and to preserve options for future generations.

Wisconsin's Biological Communities

The location and extent of biological communities are determined by environmental factors, including moisture, temperature, soils, and climate. Natural factors, especially the glaciers but also windstorms, fires, droughts, and floods, shaped Wisconsin's landscape. Human activities, beginning with Native American activities and continuing into today's intensive use of land and water, have also had profound impacts on Wisconsin's biological communities.

This report profiles seven major biological communities, which represent an aggregation of the more numerous communities described by scientists (especially Curtis) in the 1950s. These seven communities are northern forests, southern forests, oak savannas, oak and pine barrens, grasslands, wetlands, and aquatic systems.

The term **northern forest** refers primarily to location rather than to any specific species composition. Northern forests contain mixed deciduous and coniferous forests found in a distinct climatic zone that occurs north of a roughly S-shaped transition belt known as the "tension zone" that runs from northwest to southeast Wisconsin. Early forest surveys indicate that northern forests consisted of a mosaic of young, mature, and "old-growth" forests composed of pines, maples, oaks, birch, hemlock, and other hardwood and conifer species. "Old growth" is defined as a community in which the dominant trees are at or near biological maturity.

The late 19th- and early 20th-century loggers cut over virtually the entire northern forest. Conditions remaining after logging were more favorable to hardwood than to pine, resulting in limited pine reproduction after logging ceased. Today, most areas that were formerly in pine are now in oak, maple, and aspen, and the age structure of the northern forest is considerably different than it was before logging occurred. Likewise, distribution and abundance of animals in the northern forests have been altered dramatically, with some species declining in numbers and others, finding the current forest advantageous, increasing their populations.

The major biological issue relating to the northern forests is that they have been managed on a stand-by-stand basis with little regard for sustaining landscape or regional diversity. The major forest cover types are managed largely for harvest at an economically desirable rotation age, which perpetuates the limited age structure of northern forest communities. Fortunately, there is great potential for maintaining and even enhancing biological diversity in the northern forests. We have lost very few plant or animal species from the area. The key is to use a landscape approach that can produce all the successional stages, from young trees to old growth, within large and small stands in the forest mosaic.

Early European observers recognized **southern forests** (those south of the tension zone) as distinct from the northern types because of the predominance of oaks and general absence of conifers. They also noted the relative openness or park-like appearance, created by the lack of small trees and shrubs. There is evidence that these southern forests were shaped by fire in the previous 5,000-6,000 years. Beginning in the early 1800s, the southern forests were cleared for farming or harvested for lumber, fuel, and railroad ties. Fire was also suppressed. As a result, the southern forests are today severely fragmented into small woodlots. Remaining forest cover is heaviest in the southwest coulee region. The large herbivores and carnivores originally found in the southern forest, including buffalo, elk, and cougar, are gone. These species and others were unable to survive on increasingly smaller patches of appropriate habitat and were also affected by land development practices and over-harvest by settlers. Some bird species (notably the passenger pigeon) have also been lost, though many remain in reduced numbers.

Forestry practices that reduce fragmentation, increase the use of fire, and manage the old-growth forests that remain on public lands are key to restoring biological diversity on southern forests.

Oak savannas are characterized by open grassland areas interspersed with trees, especially oaks. Savannas, historically found in southern and western Wisconsin, were the gradation between the great prairies and the eastern deciduous forests. The savannas were perpetuated by fire. In the early 1800s, Wisconsin had perhaps 5.5 million acres of oak savanna, virtually all of which has been destroyed for farming and urban development or has succumbed to natural succession as fire has been suppressed. Oak savanna is now virtually nonexistent in Wisconsin, with only a few remnant areas remaining.

Many animal species associated with savannas have managed to find surrogate habitats such as wooded pastures, lawns, and small woodlots. Savanna vegetation has not fared as well. Many savanna plant species are now uncommon and found only on the fringes of oak woods, brushy areas, and lightly grazed pastures. Fortunately, oak savanna restoration is possible, through the use of fire and perhaps light grazing.

Oak and pine barrens, like savannas, depend on fire to maintain their unique character. These communities, which are found in central and northern Wisconsin where soils are poor, are characterized by sparse scrub pine or oak scattered among shrubs, brush, and grasses. In the early 1800s, barrens covered about 4.1 million acres of Wisconsin. Barrens communities have been destroyed by agriculture and urban development, or have succeeded to forests in the absence of fire. Only a few remnant areas remain. As with other communities, many of the plant and animal species associated with barrens have managed to survive, though often in reduced numbers. The potential for restoration of barrens areas on public and private lands is good if controlled burning and cutting are used as management tools.

Wisconsin's **grassland** (prairie) communities, characterized by the absence of trees and large shrubs and the dominance of grass and forb species, are at the periphery of the extensive North American mid-continent grassland biome, which lies south and west of the state. These grass-

WETLAND COMMUNITIES

AQUATIC COMMUNITIES

lands, which grew up 5,000-6,000 years ago after the glaciers retreated, were maintained by fire and probably by large grazing animals such as buffalo. Prior to Euro-American settlement, Wisconsin had about 3.1 million acres of prairies, of which almost one million acres were a wet prairie type known as "sedge meadow."

The grassland biome has been degraded throughout its range, generally from farming and grazing, but also from urban development. Some prairie areas also grew up into trees and shrubs as fire was controlled. Thus, the prairie community has been severely fragmented, with only a few remnant areas left. Prairies, along with oak savannas, are the most endangered natural communities in Wisconsin. As a result, an estimated 15%-20% of the state's original grassland flora is now considered rare here. Grassland mammals and birds adapted better, using "surrogate" grasslands such as pastures for their survival needs. Managed use of fire, removal of trees and shrubs, light grazing, and perhaps some crop production will aid prairie restoration. Populations of grassland mammals and birds can also be restored by establishing "surrogate" grassland habitat on both private and public lands.

Wetlands, which are lands on which soils or substrate is periodically saturated with or covered by water, occupied an estimated ten million acres (nearly one-third of Wisconsin's land area) in the early 1800s. Wetlands have been subject to intense modification, mainly through draining and filling for agriculture and urban development. Today, about 5.3 million acres of wetlands remain. Nearly all the remaining wetlands have suffered from the effects of fragmentation and simplification.

Current federal, state, and local regulations and land acquisition programs have considerably slowed wetland loss. However, nonagricultural filling of wetlands, especially along lake shores, continues to threaten some wetlands. In addition, the invasion of exotics such as purple loosestrife pose a threat to wetland ecology. Some wetland communities are easily restored by simply blocking drainage and allowing water levels to rise; others require decades or longer to restore natural functions.

When the glaciers receded, they left behind a variety of **aquatic communities**, including springs, ponds, lakes, streams, and rivers. Within this grouping is a wide variety of systems, differing in size, fertility (lakes), water temperature (streams), and geographic area. Wisconsin has 620 miles of Great Lakes shoreline, more than 14,000 lakes covering a total of a million acres, and more than 33,000 miles of rivers and streams, including 1,500 impoundments.

Simplification of many aquatic systems has occurred due to introduction of exotic species of fish such as carp and lamprey, which successfully compete against many native species, as well as to the large-scale destruction of shorelines and other habitats. Fragmentation has been caused by dam construction. Dams block movement of fish and other aquatic organisms, isolating populations, and sometimes resulting in loss of genetic diversity and eventual extirpation of species in a portion of the river. Dam construction also changes water flow and temperatures, resulting in changes in habitat that can lead to extirpation of species. Other activities that create pollution or cause simplification and fragmentation of aquatic systems include agricultural and urban development and resulting runoff, channelization of streams, shoreline development and resulting loss of habitat and spawning areas, and industrial and urban development and resulting effluent and runoff. In addition, some fisheries management activities such as indiscriminate stocking have also contributed to disturbance of aquatic communities.

Although the abundance of many fish species has been greatly altered, most native fish species are still abundant and self-sustaining. This relative health of aquatic communities allows us to focus attention on identifying and restoring specific degraded communities as well as protecting species with declining numbers. River and stream communities respond quickly to habitat protection and restoration. Lake communities respond more slowly. It is important to shift aquatic community management from a single-species focus to an ecosystem-management focus.

What This Report Proposes

DNR's mission is to conserve, protect, and manage both individual species and natural systems. We have a proud tradition of leadership in adapting management techniques based on the cutting edge of knowledge of natural systems. The rapid growth of new knowledge about ecosystems demands that we change the way we view and resolve management problems. Many Department employees are, and have been, using ecological principles in formulating their management actions. We need to build on our existing base of knowledge and experience.

This report, which attempts to bring together current knowledge of biodiversity and to stimulate thinking on the issue, is a step in this direction. It contains two types of recommendations. The first are broad **strategic recommendations**. These are described generally below and in more detail at the end of the next chapter. We recommend that the Department:

- Apply ecosystem management principles and practices to the Department's programs so that goals and priorities for biodiversity can be determined in the context of ecological, socio-economic, and institutional issues.

- Build partnerships with other agencies, local governments, tribes, the business community, scientists, and interest groups to accomplish common goals for ecosystem management, including specific attention to biological diversity.

- Build partnerships with private landowners to accomplish common goals for ecosystem management, recognizing that the Department cannot accomplish the breadth of what needs to be done to conserve biodiversity by working on public lands alone.

- Develop innovative and proactive information and education strategies for Department staff and the public regarding biodiversity and its relation to ecosystem management.

The second type of recommendations are **possible actions specific to each of the seven biological community types** described and assessed in this report. These are listed at the end of each of the seven biological community chapters that comprise the bulk of this report. We call these "possible actions" because they are consistent with ecosystem management but require more analysis and planning. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

> This report proposes that the best way to address biodiversity as a management issue is to apply the principles of ecosystem management to Department planning and programs. Ecosystem management is a system to assess, conserve, protect, and restore the composition, structure, and function of ecosystems, to ensure their sustainability across a range of temporal and spatial scales, and to provide desired ecological conditions, economic products, and social benefits.

A strategy for applying ecosystem management requires at least three important building blocks:

- Use the ecosystem management decision model, as described in this report, to think through alternatives and make decisions. It is a model that requires us to propose and evaluate alternative actions from their ecological, socio-economic, and institutional (laws, rules, policies) perspectives. This approach will help us frame issues in the context of their ecological, social, and economic consequences. In doing so, we will be in a better position to make decisions that include human needs and values while preserving a wide range of options for future generations.

- Use ecoregions as the geographic basis for developing consensus on regional goals for program planning. Ecoregions are large areas of the state that exhibit similar patterns in potential natural communities, soils, hydrologic conditions, landforms, lithology, climate, natural processes, and resource or land-use patterns. The ecoregion approach will enable us to set clear and measurable goals for protecting and managing biological communities.

- Use logical steps to conserve biodiversity and retain future options, using the best information we have now, while continuously evaluating and improving our approach as more information becomes available. We must make and improve decisions in the face of uncertainty. Scientists have developed a method, known as "adaptive management," to do this. Adaptive management is a formal, structured approach to dealing with uncertainty in natural resource management, using the experience of management as an ongoing, continually improving process. This process will help us implement ecosystem management at a landscape scale, using a strong science base and a clear record of why we are using particular management practices.

Some Continuing Policy Questions

Although we have identified key strategic and policy recommendations that we are ready to implement with our partners and customers, we are aware that this report will continue to raise important policy questions over time. These questions affect the balance of interests among a wide range of organizations and people. We have not identified all the implications, but we list a number of them below. They relate to issues of organization, budget, customers, skills, and management.

- How will including biodiversity as a criterion affect the balancing of multiple views in DNR decision-making?

- How do our traditional customers perceive their interests being represented within ecosystem management and attention to biodiversity?

- Are the present DNR budget structure and associated constraints flexible enough to deal with ecosystem management and biodiversity issues?

- Should we hire employees with differing skills than those we now hire if we broaden our concern for biodiversity?

- What will be the role of surrogate biological communities (e.g., switch-grass-dominated grasslands instead of multi-species prairies) or surrogate processes (e.g., clearcutting instead of burning a forest stand) in meeting our objectives for biological diversity?

- To what extent should early 19th-century native plant communities be restored? At what cost? What is biologically possible and what can be economically justified?

- How should the Department's environmental quality programs integrate ecosystem management and biodiversity concepts into their planning and permitting processes?

CHAPTER 2

Biodiversity: Issues and Implications

by James Addis, Betty Les, Anne Forbes, and Kristin Visser
assisted by Robert Dumke, Paul Matthiae, Steven Miller, Dennis Schenborn, Wendy Weisensel, and Darrell Zastrow

Importance of Biodiversity

Biodiversity is a shortened form of the term *biological diversity*[1]—the spectrum of life forms and the ecological processes that support and sustain them. Biodiversity supports the integrity of the ecological systems upon which humans depend. These ecological systems (*ecosystems*) are self-sustaining units, and to a certain extent they can absorb disturbance without suffering loss of function. However, repeated or large-scale human disturbance inevitably changes ecosystems and can threaten their viability.

Biological diversity—or biodiversity "for short"—is the spectrum of life forms and the ecological processes that support and sustain them.

Humans have a profound and continuing impact on Wisconsin's ecological systems. While some may think of tropical rainforests as the only areas where ecosystems are in danger, continuing human population growth here at home creates pressures on our natural communities. Human population growth, coupled with land development patterns and high per-capita consumption of energy and natural resources, leads to pressure on habitat from development, air and water pollution, and extraction of resources for energy and other uses. All of this can lead to loss of biological diversity.

As human populations grow and our needs and ability to use the environment increase, we will continue to alter ecological systems even though the absolute limits of ecological systems to absorb human activities are unknown. At the same time, we depend on these systems for clean air and water, food, shelter, and the raw materials that support many of Wisconsin's industries. In addition to these benefits, plants have yielded life-saving drugs, and studies of animals have provided valuable insight into navigation, biochemistry, linguistics, and medicine. Conserving biodiversity will help sustain the ecological systems that we depend on. It will also preserve options for future decision-making.

Biodiversity is complicated, occurring at many different levels. For purposes of study and management, biological diversity is usually grouped into four levels: *genetic diversity, species diversity, community diversity*, and *ecosystem diversity* (Fig. 1).

Genetic diversity consists of the spectrum of genetic material carried by different organisms. Genetic diversity within a population of a plant or animal species has the potential to change over time, allowing species to adapt to environmental conditions and retain vigor. Although genetic diversity may be expressed in visible characteristics, such as color, size, and shape, much is expressed in biochemical processes that are hidden from view. Individuals within a population carry a variety of genes. If something happens to reduce the size or variety of the gene pool, then that population's genetic diversity is compromised.

Species diversity results from the variety of *species* in a geographic area. It includes not only the number of species in

[1] Terms in italics are defined in the glossary.

Genetic Diversity

The variation in genetic composition of individuals within and among species. (e.g. variation within a population of rabbits)

Species Diversity

The variety of different species found in an area. (e.g. the variety of species found in a prairie)

Community and Ecosystem Diversity

The variety of physical environments and biotic communities over a landscape. (e.g., the variety of forests, grasslands, wetlands and aquatic systems over a region)

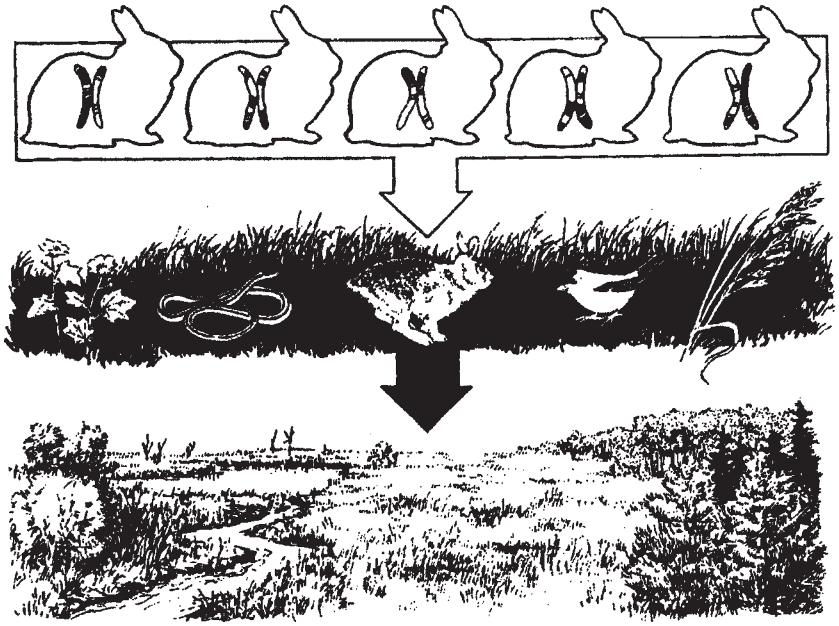


Figure 1

Biological diversity occurs at four interrelated levels, adapted from Temple (1991).

the area but also their relative abundance and spatial distribution. Species are the most familiar level of diversity because they can be classified and counted, and many, though not all, are readily visible. Species include everything from soil fungi and insects to eagles and deer, from darters to muskies, and from mosses and lichens to hemlock and red pine. Every species has a niche, or a role it plays in a natural community, defined by how individuals of a species carry out their activities, use resources, and occupy space. Understanding the niche of a single plant or animal species requires in-depth study as well as an understanding of the environment in which the species lives and interacts.

A *community* is an assemblage of species living together in a particular area at a particular time. Communities usually bear the name of their dominant plant species, for example, pine barrens, sedge meadows, and cedar glades. However, the community includes all of the plants living in association with the dominant species plus all of the animals present at a given time. Communities are often perceived as static, but they are actually in a constant state of change—change usually occurs, however, at a rate too slow for humans to note in our brief lifetimes. Communities range in size from less than an acre (e.g., shaded cliff community) to thousands of acres (e.g., mesic hardwood forest). The diversity of a given community is determined by the variety and type of species present, the intricacies of their interactions, and the age and stability of the community. The community diversity of a landscape is influenced by the number of communities present, the degree of difference among the communities, and how the communities are distributed.

> Conserving biodiversity will help sustain the ecological systems that humans depend on and preserve a wide range of options for the future.

An *ecosystem* is a dynamic complex of plants, animals, and microorganisms and their associated non-living environmental components interacting as an ecological unit. An ecosystem takes the biotic community one step further to encompass interactions with the abiotic environment, which includes moisture, temperature, oxygen, sunlight, soil, and all the other non-living physical and chemical conditions. The *biotic* (living) and *abiotic* (nonliving) *environment* interact continuously. Often, this interaction takes the form of complex processes that move gases, chemicals, and minerals in endless cycles such as the carbon cycle, water cycle, and nutrient cycle. For example, a downed tree will, through leaching and decomposition, recycle its nutrients back to the ecosystem to be used by other living organisms. The canopy gap created when the tree was downed will let in sunlight, altering conditions on the forest floor and providing opportunities for new plant species to become established. While all this is happening, the tree is providing shelter for mice and salamanders, food for invertebrates, and substrate for plants. This tiny ecosystem exists within a much larger forest ecosystem that might encompass thousands of square miles. In this larger system are hundreds of species of plants, hundreds of animal species, and probably thousands of species of microorganisms. Ecosystems are constantly changing in response to short-term human impacts such as timber harvest and naturally caused perturbations such as fire or disease, along with long-term influences such as climatic change.

The interactions that connect microorganisms, plants, and animals with the nonliving environment are all part of biological, physical, and chemical cycles that have been occurring on Earth for millions of years.

Within ecosystems, the processes of ecological *succession*—that is, the progressive changes in species composition, organic structure, and energy flows over time—are also constantly at work. Large ecosystems contain a mosaic of successional stages—a forest may have large areas of fully mature trees, but will also have open areas with shrubs, patches of young trees growing up after a blowdown, and other vegetative communities within the larger matrix of the mature forest. Ecosystems are in turn part of the larger *landscape* of adjacent and interacting ecosystems. Surrounding lands can significantly affect the character of an ecosystem; therefore, ecosystems must be considered within the context of the broader landscape.

Wisconsin is blessed with great biodiversity. Located at the junction of three of North America's *six biotic provinces*—the eastern deciduous forest, the northern boreal forest, and the temperate grasslands—we have a wealth of species and natural communities. Curtis (1959) delineated 21 major plant communities for Wisconsin, plus 13 lesser communities restricted to small areas. Approximately 1,800 native vascular plant species are known in Wisconsin, along with 657 species of vertebrates. In addition, there are thousands of species of nonvascular plants and invertebrates. DNR's challenge is to work with Wisconsin citizens to conserve this biological wealth.

Wisconsin is located where three of North America's great natural borders join. Here, East meets North and West to create a wealth of biological diversity. It is DNR's challenge to work with Wisconsin citizens to conserve this natural heritage.

Historical and Current Perspectives in Resource Management

Throughout the history of natural resources management, decisions have been based in part on the personal values of individuals. Today, each DNR employee has a personal history and set of values related to natural resource management. Consider, for example, a group of managers standing on a hillside looking out over an expanse of land below. One person notes the low mounds and plains that indicate glacial topography. Another's eyes go straight to the creek meandering through the scene; this person wonders what fish are present and if they get to any size. Another person in the group spots a small plot of millet growing on the otherwise fallow land and comments that it's probably a wildlife food patch. Yet another scans the land with binoculars, looking for wild flowers and signs of any unusual habitat. Some think of this piece of land as potentially something to manage for a natural "product" such as grouse; others in the group think of it primarily as something to preserve or to restore to its original natural condition. If they examined their personal feelings about the land, some would discover that they view themselves as part of the land. Others would discover that, while they appreciate and respect the land, they view themselves as separate from it, as its manager or steward. All of these individuals are natural resource professionals, and while they have many things in common, they also have obvious differences. Most of these differences are due to training, experiences, and *values*. A variety of values about the environment have prevailed during different periods of history.

Development of Conservation Ethics: 1850s to 1950s

Current environmental values and viewpoints are rooted in two different schools of thought that developed in the latter half of the 19th century. These are often referred to as the preservation ethic and the conservation ethic.

The **preservation ethic**, first articulated by Ralph Waldo Emerson and Henry David Thoreau in the mid-1800s, and later espoused by John Muir and others, focused on the spiritual value of nature and viewed its preservation as a moral obligation. The

Each DNR employee has a personal relationship to natural resource management. As a group of managers stand on a hillside and look over an expanse of land below, each will see the same scene through the filters of their personal experiences, traditions, and values. If we come to understand the historical roots of our traditions and values in resource management, we may better understand the perspectives of others and work with diverse views to find solutions.

> We do not need to choose between preservation and conservation. Rather, they each have a role to play as we create an overall set of principles for managing resources.

preservation ethic was a reaction to the large-scale urban, industrial, and agricultural development that seemed to Emerson, Thoreau, and Muir to be crowding out natural environments. This ethic viewed nature as having intrinsic value apart from its utilitarian value. Thoreau's statement that "in wildness lies the preservation of the world" sums up the preservation viewpoint. Although the movement created a tremendous awareness of natural beauty and succeeded in preserving some of our nation's most scenic landscapes, it did little to stem the exploitation of species. However, this spiritual valuing of nature remained a strong theme throughout the 20th century and became entwined with the resource conservation ethic in many ways. It is the philosophical foundation for the way that many managers and citizens relate to the environment today. In Wisconsin, the preservation ethic sparked the establishment of Wisconsin's first state park in 1900 and the identification of other areas of natural beauty to be purchased in succeeding years. In 1907 the State Park Board was established to oversee this task. And the nation's first Natural Areas program began in Wisconsin in 1951.

The prevailing source of values in natural resource management for the past 100 years or so has been the resource **conservation ethic**. This ethic grew out of the crisis created by the overexploitation of nature that occurred during Euro-American settlement. As fish and wildlife populations were decimated and the forests reduced to stumps, the public demanded government intervention. As a result, the first conservation agencies were formed. Although these first managers had little formal training in science or natural resources, the subject matter of their work gradually made its way into colleges and universities as the need for trained managers increased and as the complexity of the work became evident.

In Wisconsin, the conservation ethic was expressed in the establishment of departments, boards, and commissions to protect and manage the state's resources. In 1903, a State Forestry Department was established, followed by the first forest ranger school and game warden school in 1911-1912. The Wisconsin Conservation Commission and Conservation Department were created in 1915, pulling together boards and commissions covering parks, fish, game, forests, and law enforcement.

These first managers focused their work on fish, wildlife, trees, and other resources that had potential for regeneration. Their job was to manage these highly utilized resources for the "greatest good," to benefit the greatest number of people over the long term. Conservationists did not advocate preservation for its own sake. They believed that careful management could produce a sustained flow of benefits with an emphasis on valuable species such as deer or pine trees. The motto of the conservation ethic became "wise use" or "use without abuse." Finely honed professions developed, each specializing in a particular resource. As the professions became more scientific, they also became more quantitative. This increased technical orientation plus the passage of time may have obscured the basic value lying at the core of these professions, but the resource conservation ethic was continuing to exert a profound influence.

Aldo Leopold's **land ethic** transcended both the resource conservation ethic and the preservation ethic. The land ethic, which Leopold articulated just before his death in 1948, focused on the interconnectedness of nature and the rightness or wrongness of human interaction with nature. Leopold's simple but compelling statement that "the destruction of land, and the living things upon it, is wrong" sums up the basic premise of the land ethic. The land ethic grew out of Leopold's personal experience as a forester and game manager practicing traditional techniques of range management, predator control, and user regulations. The land ethic does not oppose human use of nature or scientific management of natural systems; in fact, it assumes both. What matters is how we go about our use and management of nature. According to the land ethic, it is in the self-interest of humans to treat the land well since we are part of nature and our well-being depends upon it. Leopold's work led to an awareness that management actions have far-reaching and often unpredicted consequences and that the natural world is far more complex and interrelated than scientists had previously realized. This thinking was gradually integrated into the developing science of ecology and called for a new consciousness regarding our relationship to the land.

The Turning Point: *Silent Spring*

The decades since the emergence of Leopold's land ethic have seen a variety of landmark events concerning the environment and natural resources. Foremost among these was the publication in 1962 of Rachel Carson's book *Silent Spring*. This book raised the specter of a soundless spring—a spring without insects, invertebrates, frogs, birds, and other animals—and brought home the meaning of the effects of pesticides in complex food webs. Its publication marked an end to a period of innocence for the American public. The notion that we could load the earth with chemicals and wastes with no consequences gave way to a more sober, realistic view of limits and harm. As more evidence of damage surfaced, public pressure to regulate pollution increased. This new public concern focused on the environment as a whole rather than the species orientation that had dominated decades earlier. In 1967 Wisconsin became the first state to ban the pesticide DDT. At the national level, comprehensive environmental legislation (Environmental Policy Act, Clean Water Act, Clean Air Act) was put in place. This legislation added a new dimension to natural resource management and led to the creation of new environmental protection professions.

> "The land ethic simply enlarges the boundaries of the community to include the soils, waters, plants, animals, or collectively: the land." (Aldo Leopold, The Sand County Almanac)

The Growth of Environmentalism: The 1960s and 1970s

For natural resource professionals, the environmental movement of the 1960s added new values to the preservation ethic, resource conservation ethic, and land ethic. This new set of values has been termed the **environmental protection ethic**. This ethic views the environment as a set of physical systems that must be maintained in a healthy, functional state. Regulating pollutants going into systems, monitoring movement of pollutants within systems, and predicting their impact are prime concerns for natural resource managers working in environmental protection. Concern for species was not left out of this period; in fact, the reasons for the decline of species was now seen in the larger context of environmental damage. The Endangered Species Act of 1973 provided a legal means to conserve the ecosystems which support endangered species and threatened species. This act also gave expression to Leopold's adage that "the first rule of intelligent tinkering is to save all the parts."

Multiple values, often appearing as incompatible, were simultaneously developing among citizens. For example, one value held that we must protect the environment for future generations. Another held that we must protect the environment primarily for present economic benefits. Individuals with this latter viewpoint often saw human qualities as separate and "at the top of" nature, giving people special rights and responsibilities. An opposing viewpoint saw nature as having value in its own right and violation of nature as immoral; humans were seen as just one part of nature, perhaps a small and inconsequential part in the total scheme of things. The result was lively and intense public debate, but no clear or unified vision developed to guide policy decisions. The first Earth Day, led by

The notion that we could load the earth with chemicals and wastes with no consequences gave way to a more sober, realistic view of limits and harm and paved the way for the environmental protection ethic.

In 1967 the Executive Branch Reorganization Act brought together closely related traditional conservation tasks and newly emerging environmental protection responsibilities to create the Wisconsin Department of Natural Resources.

Wisconsin U.S. Senator Gaylord Nelson, was held in 1970. This event drew many people into the debate and widened the base of support for environmental protection.

During this period, single-species management was still the rule in resource management, but the strong Aldo Leopold tradition in Wisconsin was also being felt. For example, wildlife and fisheries managers who were aware of the value of wetlands for a wide spectrum of species (not just target species like ducks or northern pike that the public normally associated with wetlands) broadened projects to benefit the system as a whole. Acquisition of land adjoining trout streams in the Central Sands counties not only protected the stream habitat and allowed fishing access but also protected the bottomland vegetation adjacent to the stream. Land acquisition for watershed protection also began in this era.

Although Wisconsin had regulated pollution as early as 1927, when the State Committee on Water Pollution was created, the 1960s marked the beginning of a tremendous increase in programs devoted to the environment. Much of this was due to the formation of the Wisconsin Department of Natural Resources, which occurred in 1967 when the Executive Branch Reorganization Act, developed under the guidance of the Kellett Commission, became law. This law brought together closely related traditional conservation tasks and newly emerging environmental protection responsibilities. It merged the Department of Resource Development, air pollution functions of the State Health Board, and the Wisconsin Conservation Department to form a single state agency.

The merging of these programs also meant a merging of administrators and managers with different historical influences, values, and approaches to problem-solving. The new DNR organization reflected these differences. For example, the Division of Resource Management was organized into separate bureaus for management of fisheries, wildlife, endangered resources, forestry, and parks, with research and property management functions providing support. The Division for Environmental Quality was organized around the major abiotic components of the environment (air, water, land), emphasizing their management and regulation, mostly through permit control.

Emergence of Concern for Biological Diversity: 1980s-Present

The next major step in the evolution of natural resource management occurred in the 1980s, when public concern for loss of natural spaces and rapidly increasing scientific knowledge about the interconnectedness of all the pieces of ecosystems merged to produce both public and scientific interest in managing resources with the goal of conserving biological diversity. This increased concern for biological diversity cannot be attributed to any given person or group. Indeed, the thoughts of many people from around the world—scientists, managers, philosophers, and the public—contributed to its development. Scientists have come to understand that some concepts—especially the idea that ecosystems reach a "steady state" or "climax" condition—do not provide an accurate picture. This correction to an established assumption has led to questioning some established management principles and activities. These changing concepts of management place new and challenging demands on DNR employees and the agency as a whole.

The conservation of biological diversity became the next major step in the evolution of natural resource management.

Throughout 1993 and 1994, discussions with DNR staff, county forest administrators, leaders of groups representing business, environmentalists, hunting and fishing organizations, academics, and members of the public have shown us that

Wisconsin residents do indeed hold a wide range of opinions about biodiversity. Most people we spoke with do agree on a definition of biodiversity similar to the one used in this report. Most feel that biodiversity is a serious issue, brought to public attention by a combination of both advances in scientific knowledge and public concern for loss of wild and natural places. Some believe that changes in management must be made, but that we have time to think through changes and make incremental changes. Others feel that resource managers have not adequately considered biodiversity in their decisions, and that there is an urgent need to revise management practices and to set aside large biodiversity reserves to protect ecosystems. Still others are concerned that biodiversity is too complex a concept on which to base management actions. They may want to manage to conserve biodiversity but are unsure what actually needs to happen "on the ground." Some people we've spoken with feel that concern for biodiversity is just a fad, others think of it as the newest environmental buzzword, and some said that resource management professionals have been managing for biodiversity all along.

Those with whom we spoke do agree that ignoring issues until inflexible positions have been staked out is not the way to handle biodiversity issues in Wisconsin. Factual data analysis together with open-minded dialogue among citizens of diverse perspectives will be required to develop a consensus for policies that integrate ecology, economics, and human values. Biodiversity and economic health must not be seen as conflicting; they must be integrated into rational resource policies that will enhance the lives of present and future generations. The practice of ecosystem management, as described later in this chapter, will play an important role in bringing this integration about.

DNR's Role in Conserving Biodiversity

By creating the Department of Natural Resources, the Wisconsin Legislature recognized the need for an integrated approach to protecting, conserving, and enhancing Wisconsin's environment and natural resources. The legislature further recognized that the needs of traditional conservation programs and environmental programs were closely interrelated and that forming a single agency would provide better management and greater public benefit. Thus, the Department's mission statement reflects this holistic approach:

- Protect and enhance our Natural Resources—our air, land and water; our wildlife, fish and forests.
- Provide a clean environment and a full range of outdoor opportunities.
- Insure the right of all Wisconsin citizens to use and enjoy these resources in their work and leisure.
- And in cooperation with all our citizens to consider the future and those who will follow us.

Managing to conserve biological diversity helps the Department carry out this mission. Although biodiversity was not a common term until recently, the Conservation Act of the early 1920s provides the direction required for our present-day response to biodiversity as a management issue. Chapter 23.09 of the Wisconsin Statutes states that "the purpose of this (conservation) section is to provide an adequate and flexible system for the protection, development, and use of forests, fish and game, lakes, streams, plant life, flowers, and other outdoor resources in this state." The balance of protection, development, and use of our natural resources demands that we conserve the long-term functional health of ecosystems, including their biological diversity.

Wisconsin citizens hold a wide range of opinions about the conservation of biodiversity. Most people who shared their thinking with us agreed on a basic definition of biodiversity similar to the one in this report. This common ground will be important as we seek to integrate ecology, economics, and human values in resource management policy and practice.

Ecological Issues

Plants, animals, and humans colonized Wisconsin as the glaciers receded 10,000-12,000 years ago. The earliest archeological evidence of human presence in Wisconsin dates from 11,000 years ago. Thus, the biotic communities that took hold in Wisconsin after the glaciers receded were influenced by human activity from the beginning. The size of the human population in Wisconsin in the millennia before European contact is a subject of speculation. At one time the settlement of Cahokia, in southern Illinois, supported a population of perhaps 30,000 individuals. We can assume that pre-Columbian Wisconsin also had a large human population, although there is no evidence that communities the size of Cahokia were located here.

The native populations managed the landscape to produce food, fiber, fuel, and other needs. We do not know how much land might have been in agriculture, but there is archeological evidence of irrigation, raised beds, and other intensive farming practices. Farming and the use of fire for agricultural clearing and for managing animal and plant populations were possibly the most significant factors affecting natural succession of plant communities in Wisconsin. In northern Wisconsin, native populations hunted and fished intensively, and impacted the northern forests through gathering firewood, creating clearings for settlements, favoring plants useful for medicine and food through cultivation and management, and using forest materials for tools and shelter.

When Europeans landed in the New World, this picture changed dramatically. Native populations lacked immunity from such diseases as smallpox, influenza, measles, venereal diseases, and the common cold. Beginning in 1492, disease spread along trade routes even to tribes that had no direct contact with Europeans. Throughout North, Central, and South America, native populations declined dramatically due to disease epidemics. When Europeans arrived in Wisconsin in the 17th century, they found a much smaller human population than had existed two hundred years before. The result was that much of the area may have become more "natural" due to less human management and use.

The first Euro-American settlers, arriving in Wisconsin in the 1830s and 1840s, found a landscape characterized by extensive forests, grasslands, wetlands, and a variety of other biotic communities. While the species of plants and animals the Europeans found here had adapted to Wisconsin's soils and climate over thousands of years, they had done so in the presence of humans who were continually affecting the landscape to the extent allowed by their population size and their technology. Europeans brought technologies of the industrial age that began more intensive manipulation of the environment. They also introduced, both purposefully and accidentally, many non-native plants and animals to compete with the native species, often resulting in broad changes in ecosystem composition, structure, and function.

Today, Wisconsin's landscape reflects a high degree of human use. It is a mosaic of urban areas (cities, towns, suburbs), production areas (farms, mines, industries, commercial forests), multiple-use areas (parks, lakes, public forests), and protected natural areas (conservancy, wilderness). This patchwork bears little resemblance to the landscape the native populations knew, or to the one the first European explorers saw.

Managing Wisconsin's natural resources to conserve biodiversity requires that we understand how today's patterns of land and resource use were created from these earlier landscapes and how human activities and natural processes continue to produce those patterns (Fig. 2). The activities and processes of particular concern in relation to biodiversity can be grouped into three major categories: ecological *simplification, fragmentation,* and *environmental pollution*. While *simplification* and *fragmentation* result from both natural

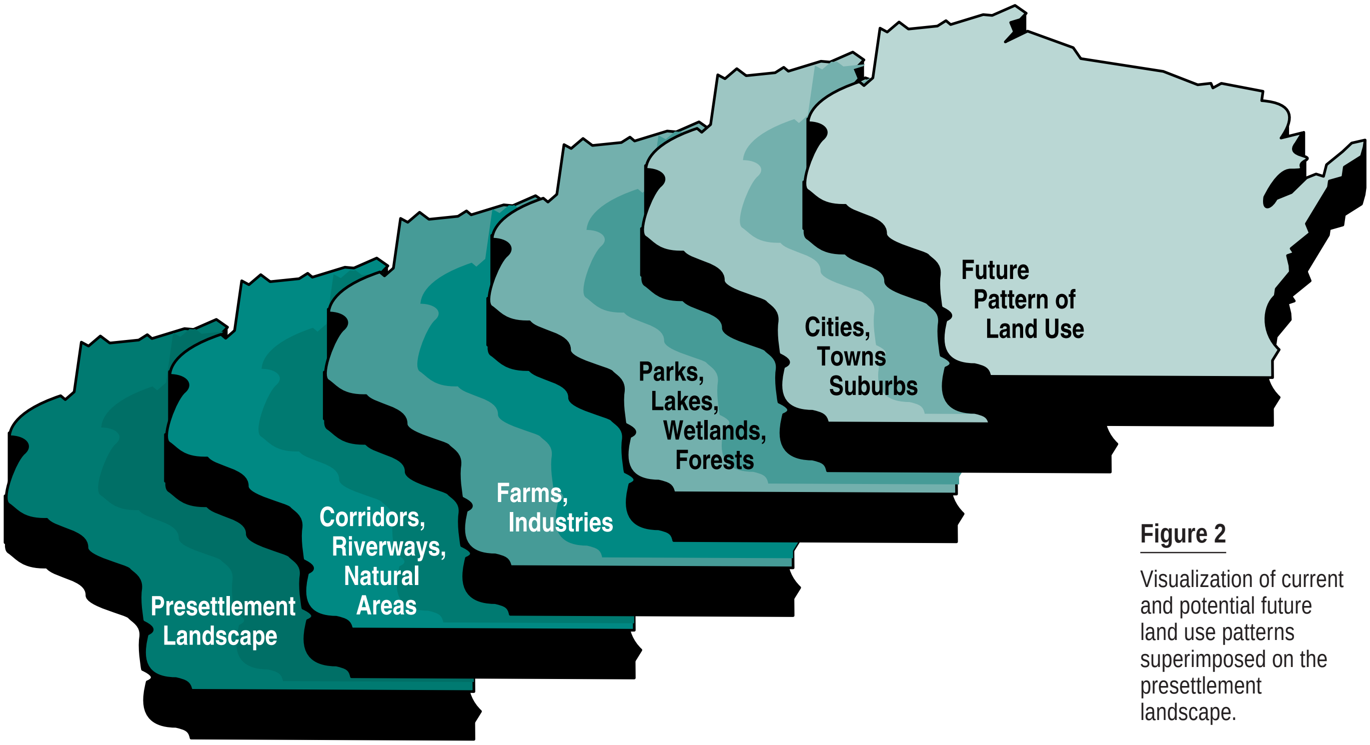


Figure 2

Visualization of current and potential future land use patterns superimposed on the presettlement landscape.

and human-caused events, human actions tend to alter the ecosystem at an increased rate and at a greater magnitude than natural events do. Certain species, communities, and ecosystems are not doing well in Wisconsin because of these human-caused changes. In contrast, populations of generalist species that are well adapted to the simplified or fragmented environment are flourishing. *Environmental pollution*, which is almost entirely a result of human activity, also poses formidable threats to biodiversity. Although the effects of pollution on ecosystems are often similar to those caused by simplification and fragmentation, the causes and mechanisms of pollution are very different. Understanding simplification, fragmentation, and environmental pollution will help us understand the ecological trade-offs and consequences of our decisions and will help define the institutional, social, and economic choices that will be made in the future to guide DNR's activities in relation to biodiversity.

> Our goal is sustainable ecosystems in the context of today's landscape. Knowledge of the presettlement vegetation will help us recognize the ecological potential of an area and answer questions about how, how much, and where biodiversity can be restored.

Although this report focuses on natural vegetation and natural communities, we also need to consider urban and agrarian systems as we continue to move forward to ecosystem management, because humans are an integral part of the environment. Our goal is sustainable ecosystems—whether highly modified by humans or largely natural—that maintain ecological *composition, structure*, and *function* and maintain genetic, species, community, and ecosystem diversity across all land uses.

For natural communities, early 19th century vegetation can be used as a guide for restoration that provides valuable insights into the ecological potential of an area. Although recreating this former state would be an unrealistic goal given current conditions (except in some natural reserves), it is important to understand what was here in the era prior to Euro-American settlement. This period represents a time when scientific biological observation began, when native plant communities were less disturbed by management activities and fairly undisturbed by the many species of non-native plants and animals. This information can guide us as to what elements of biodiversity can be protected and restored, in what levels of abundance, and in what geographic areas, helping us reach our goal of sustainable ecosystems in the context of today's landscape.

What follows is an overview of ecological simplification, fragmentation, and environmental pollution, with an emphasis on explaining what these concepts mean and how they impact biodiversity. The concept of scale provides a foundation for understanding how to deal with these issues (see inset).

Scale

Scale is the relative amount or degree of something, often expressed in terms of a progressive classification as to size, complexity, or importance. In management of natural resources, scale is often used to describe the scope of a management action—whether site-specific, local, regional, or statewide in space, and annual, seasonal, or successional in time—and the degree to which the management action alters the existing plant and animal communities.

Thus, when the concept of scale is applied to ecosystems, it has both spatial and temporal meanings. *Spatial scale* is used to describe the geographic size of a community or ecosystem (Fig. 3). This size can range from a microsite such as the underside of a leaf on the forest floor, to the entire forest, to the larger landscape. The biosphere, including earth, its enveloping air mass, and all its biota can be thought of as the largest scale from a biological point of view. *Temporal scale* describes the time required to complete a life history event or an ecological process, such as the a series of successional stages (Fig. 4). For life history events such as life cycles, temporal scale can vary from a few hours for certain microbes and insects to thousands of years for ecosystems. Ecological processes can vary from a few seconds for individual biochemical reactions to decades for forest regeneration. When tied to geologic changes, temporal scale reaches millions of years.

For ecological purposes, the amount of detail with which an ecosystem can be described for management planning is determined by the spatial and temporal scales. Due to time and resource constraints, we are often able to provide more detail at smaller scales than at larger scales. We often speak of this situation using the term resolution, i.e., as having a high degree of resolution at small scales and a low degree of resolution at large scales. For example, in an endangered plant inventory of a very small plot, we may be able to thoroughly sample the plot inch-by-inch. An inventory of a large area would be done at a lower degree of resolution, perhaps by running transects at intervals across the area. The former sampling approach gives us a lot of information about a very small area, and the latter gives us less detail but includes a wider geographic area and a larger amount of total information on plant distribution.

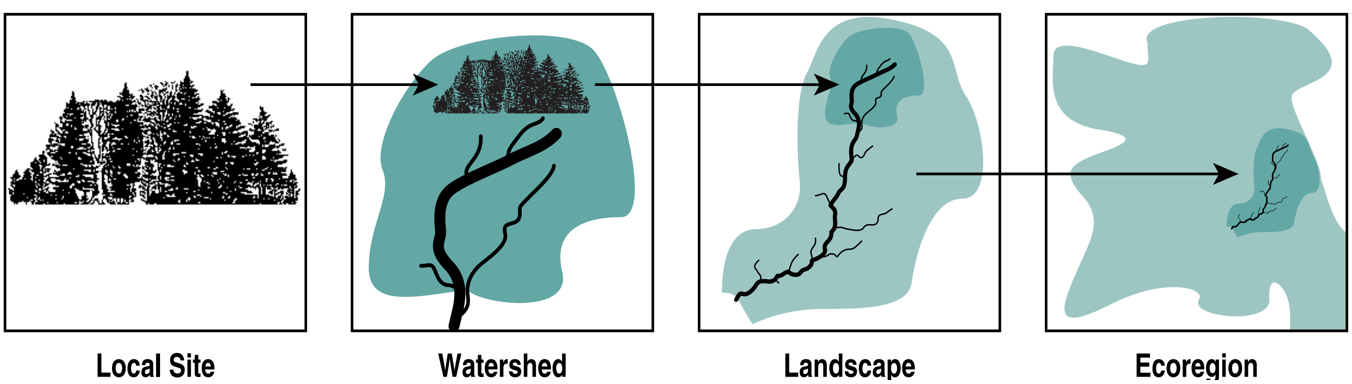
The desired spatial scale for overall *ecosystem management* planning is the *landscape*. A landscape is an area composed of interacting ecosystems that are related due to underlying geology, landforms, soils, climate, biota, and human influences. Broad management goals will be set at this scale and will relate to relatively large geographic areas, using the information collected with a low degree of resolution, or less detail, as described above. Management of specific sites within the broad landscape will occur based on goals set at the landscape scale. Information with a high degree of resolution will be collected at specific sites as needed to check the accuracy of goals set on the landscape scale or to fine-tune management plans for specific sites.

Landscape-scale management encourages us to approach problems and projects using the broadest scale with ecological meaning. Thus, the geographic area or *region* included in any particular analysis will be determined by our knowledge of the breadth of the interconnections among the biotic communities involved. For example, a proposal to create a new Natural Area in Wisconsin for the protection of biodiversity would include a series of considerations—among these are the size and quality of adjacent buffer areas needed to protect ecological integrity on the site; the relative importance of the site to biodiversity within a statewide view of community and ecosystem status; and concerns such as the transport of pollutants or the condition of migratory bird habitats on continental or inter-continental scales. Or, a proposal to acquire land to support an anadromous sport fishery on the Great Lakes would include an analysis of the ecological conditions of all the streams and watersheds on the Wisconsin shoreline of Lake Michigan and/or Superior. The analysis would indicate how the overall management plans for these streams address statewide issues of biodiversity as well as other important related issues such as recreation and water quality.

Biodiversity is maintained by the presence of an array of communities and species occurring within ecosystems which are intact and sustainable, that is, they usually contain a wide range of species and natural processes. The appropriate scale for management must be considered and deliberated along with other considerations if biodiversity is to be preserved or enhanced. If we are not aware of the concept of scale in planning a proposed action or do not understand the implications of our choice, we run the risk of developing inappropriate plans and prescriptions. Worse, we can unknowingly change the community or ecosystem involved. These choices are complex, for decisions that favor increasing diversity at a given scale may decrease diversity at other scales.

Figure 3

Examples of spatial scales can be observed with the "nesting" of small areas, such as a local site, within progressively larger geographic units.



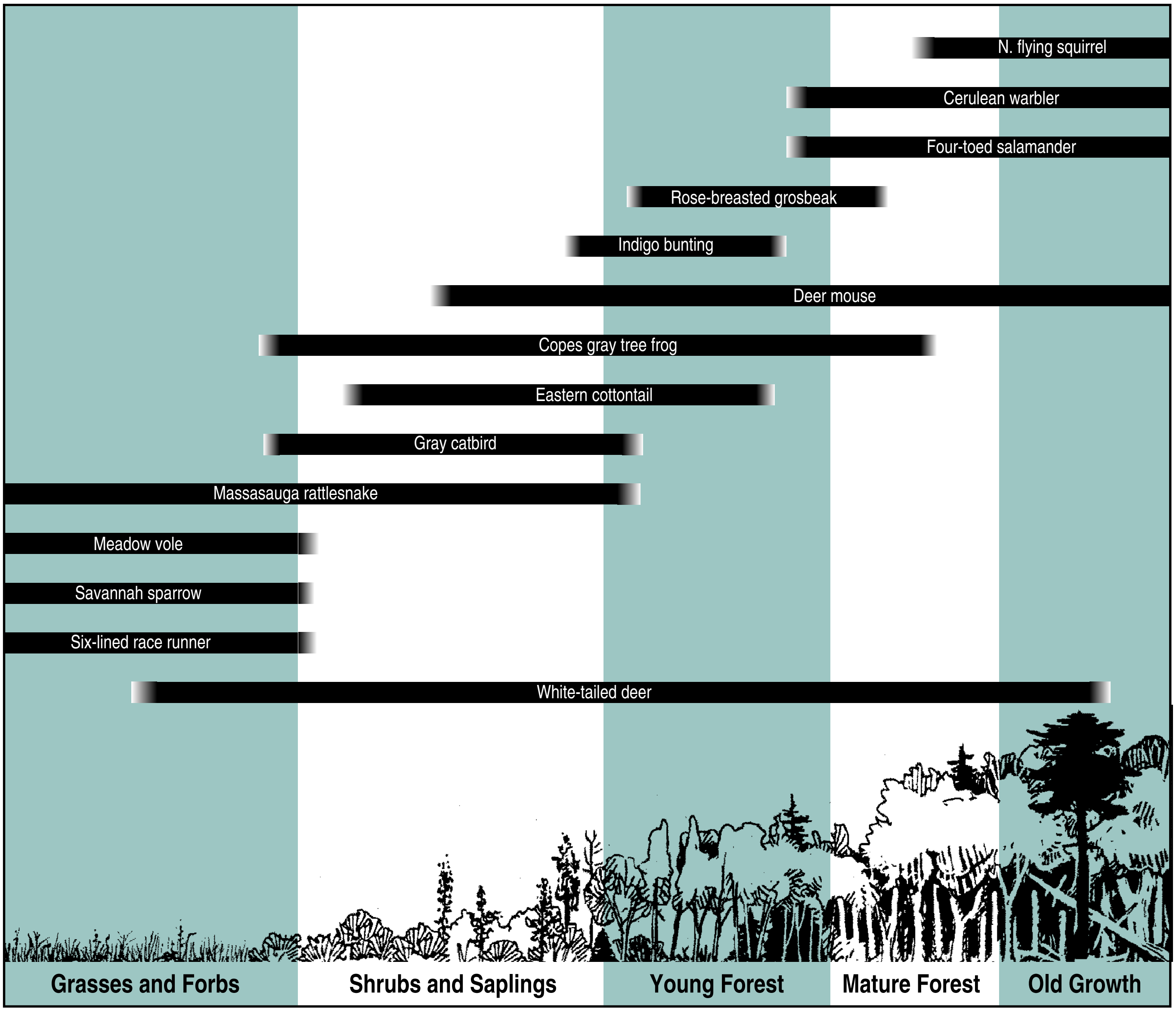


Figure 4

Examples of temporal scale can be observed with the succession of a southern Wisconsin grassland to a forest. The composition of plant and animal communities change along with the landscape. Adapted with permission from material produced by the Minnesota Department of Natural Resources.

Ecological Simplification

Ecological simplification means that the interrelationships between organisms and their environments are reduced in number and complexity. Simplification can be caused by habitat loss, non-native species encroachment, air and water pollution, and many other factors. Although the effects of simplification are complicated and often subtle, they are often discussed in terms of their impact on the three major attributes of ecosystems: *composition, structure*, and *function* (Fig. 5).

Composition

Composition refers to the fundamental elements of natural systems—the specific organisms or groups of organisms that a unit area or geographic area contains. At the statewide level it includes ecosystems, communities, species, and their genetic composition. Thus, an ecological system simplified in terms of composition might have reduced numbers of species present or a limited gene pool for a remnant or isolated species.

The most radical impacts on composition occur when there is total destruction of the biotic, abiotic, spatial, or temporal needs of species. The conversion of native prairies, savannas, wetlands, and southern forests to agriculture and urban development since Euro-American settlement are among the most conspicuous examples.

The introduction of exotic species provides another example. Purple loosestrife, known to exist in restricted areas of Wisconsin's wilds for over 40 years, has spread across three-quarters of the state in ten years, seriously simplifying many wetlands. Garlic mustard has invaded southern Wisconsin forests, displacing native forbs and dependent fauna. Common buckthorn and Japanese honeysuckle have invaded southern mesic and dry mesic forests, while glossy buckthorn has invaded wet forests and bogs. All three have displaced forbs and shrubs, and in bogs even established trees are being lost to competition. In some southern Wisconsin oak forests, buckthorn and honeysuckle encroachment has begun to significantly reduce oak regeneration. Similarly, the rusty crayfish, introduced as sport-fishing bait, has spread to a large number of inland lakes, displacing native crayfish and disrupting entire plant communities. The result has been an adverse impact on other fauna such as fish, invertebrates, and zooplankton that are dependent upon the aquatic macrophytes consumed by the rusty crayfish.

> When ecosystems are simplified, we may observe a reduction in species numbers, their gene pools, the physical structure of their habitats, or the complexity of life-sustaining processes such as food webs or water cycles.

Thus, the presence of non-native species within terrestrial and aquatic communities and ecosystems often leads to displacement of native species and change in ecosystem function. Displacement is usually not one for one; one exotic species can displace many native species. Because exotics are generally introduced without consideration for natural biological and ecological controls, once they "escape into the wild" they sometimes prove very successful in competing against native species. Today, an estimated 22% of Wisconsin's 2,300 vascular plant species are non-native species.

Structure

Structure refers to the pattern or physical organization of an area; it is used to define physical appearance both vertically and horizontally. Vertical stratification is readily visible in a mesic hardwood forest, where one group of species occupies the canopy layer, another group the subcanopy, another the sapling layer, and so forth, down through shrubs, tall herbs, short herbs, and ground cover (surface) plants. Horizontal variation occurs across the length and breadth of any community or, at a larger scale, across sub-regional and regional landscapes. Canopy gaps, forest

Figure 5

The three major attributes of ecosystems: composition, structure, and function. Ecological simplification occurs in relation to all three.

Composition

The make-up of an ecological unit, including the specific organisms or groups of organisms in a particular area.

Structure

The pattern or physical organization of an area. It has both vertical and horizontal components.

Function

The roles that the living and nonliving components of ecosystems fulfill in driving the processes that sustain ecosystems.

A simplified ecosystem has little of the structural complexity that creates diverse habitat opportunities as a basis for ecosystem function.

openings, seasonal ponds, savanna alternating with prairie, riffles alternating with slow water, and backwaters adjoining main streams are all examples of horizontal variation. The location of vegetation in a horizontal plane is related to the slope, exposure, soil, proximity to other plants of the same or different species, and dispersal mechanisms. Vegetative debris—fallen trees and limbs, standing dead trees, and leaf and forb litter—is also part of a community's horizontal and vertical structure.

Animals follow a pattern of vertical and horizontal organization similar to plants. For example, birds and invertebrates that occupy the canopy of a forest community differ from those that occupy the midlevel, many of which differ from those residing on the forest floor. Similarly, the fauna associated with a lake's emergent vegetation differ from the animals associated with the floating or submerged vegetation.

A simplified ecosystem has little of the structural complexity that creates diverse habitat opportunities as a basis for ecosystem function. For example, a forested area being managed on short rotation for even-age, single-species trees is a structurally simplified system. Because the tree species are all of similar age and are cut before other layers of vegetation can become well established, there is little vertical or horizontal layering. Animal species inhabiting the area would likewise reflect lower diversity than would be found in a forest with trees of various ages.

Function

Function refers to the roles biotic and abiotic components of ecosystems (e.g., producers, consumers, digestors, transformers, water, minerals, and microclimates) fulfill in driving the *ecological processes* (e.g., water and carbon cycles, mineral and nutrient cycles) that sustain the ecosystem. Every naturally occurring organism within an ecosystem has one or more roles in sustaining the dynamics of that ecosystem. For example, on an ecosystem or landscape scale, vegetation controls the community environment, is the primary source of energy for other organisms within the community, and is the principal source of minerals and chemical compounds necessary to sustain animal life. Animals are the main consumers, with primary consumers eating plants and secondary consumers eating other animals. Still other plants and animals along with fungi and bacteria perform essential functions as decomposers and transformers of waste products and detritus, converting dead material back into elements essential to plant growth. Each individual plant and animal has a functional role in the support of other species and the community as a whole.

Increased diversity and functional complexity generally provide resilience to ecosystems. Conversely, for a given ecosystem, reduced biological diversity may result in less resilience. In less biologically diverse systems minor changes in energy flow or population structure produce major changes in energy transfer and populations. Unpredictable and chaotic changes may occur. A community will cease to be part of a viable ecosystem if there is significant functional loss. The Lake Winnebago system provides a good example. An increase in water level in the system and other factors led to a severe reduction in aquatic plant populations beginning in the late 1800s. Wind and wave action across these large expanses of water prevented macrophyte reestablishment by increasing turbidity, eroding the shoreline, and uprooting plants. Populations of invertebrates, fish, and waterfowl have fluctuated through the years with a general trend toward decreasing numbers. Numerous attempts to manage the water level have met with limited success due to the great functional losses to the system. A system-wide approach is now being taken through DNR's Lake Winnebago Comprehensive Management Plan and offers a much better chance for improvement.

Fragmentation

The natural variation of biological communities across a landscape, often referred to as "natural patchiness," has always been a normal part of the environment. At the time of Euro-American settlement, the natural landscape of Wisconsin was broken up into wetlands, prairies, forests, lakes, and streams, all occurring in numerous patches of varying sizes. Some species, such as prairie chickens, thrived only on very large patches of suitable habitat. Others were more successful at the interface edge between plant communities and took advantage of two or more habitat types—for example, the white-tailed deer which uses forest, brushland, and prairie edges.

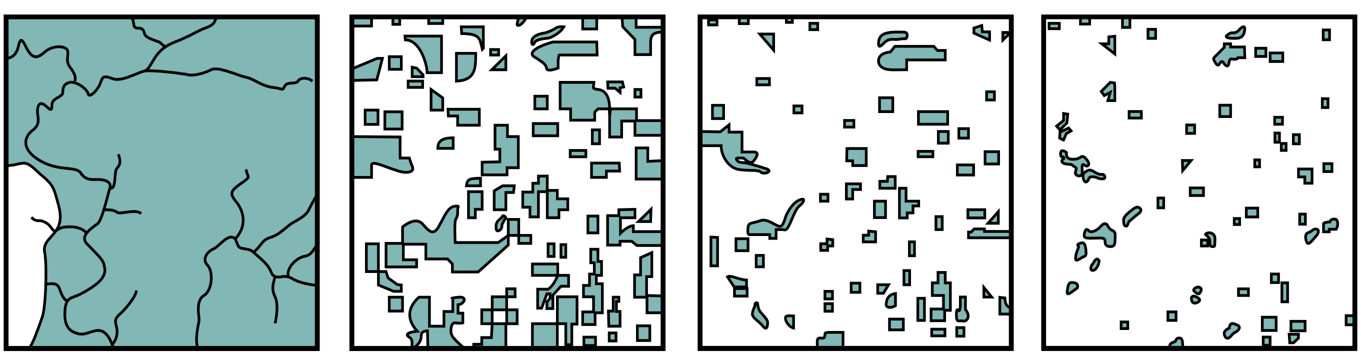
Many animal species need a high degree of "patchiness" because their life requirements are met by using different habitats at different times. Others, such as grassland birds and interior forest songbird species, are favored by relatively large, continuous habitats of similar vegetation. More subtle differences in soil, microclimate, moisture level, slope, and aspect permit plants to thrive in one area and not another. For example, the northern forest ecosystem includes numerous communities representing a range of successional stages as well as natural patches of oak, aspen, balsam fir, and tag alder, which under natural conditions gradually blend one into another. This "patchiness" may often protect plants from catastrophes such as disease, insect outbreaks, and fire.

Natural landscapes gradually merge one habitat type with another or leave corridors or ways for animals to move and still stay in their preferred habitat. Fragmentation is the breaking up of large and continuous ecosystems, communities, and habitats into smaller areas surrounded by altered or disturbed land or aquatic substrate. Fragmentation eliminates corridors and causes the abrupt meeting of different habitat types. In Wisconsin human activity has greatly fragmented the landscape, producing changes that are different from natural landscape heterogeneity or patchiness. For example, during Euro-American settlement the northern forests were logged and many areas were burned, leaving only scattered "islands" of forest remaining. These disturbances in the north occurred within a 50 year time period. After that time, the land-use pattern remained "undeveloped" in character and the land progressively grew back to forest. As agriculture and urbanization grew in southern Wisconsin, the southern forests, prairies, and wetlands were broken into increasingly smaller and more isolated fragments that remain today. Roads, sewer, and utility corridors; dams; residential, commercial, and industrial development;

> In order to observe fragmentation of biological communities or ecosystems, we look at the pattern of fragments on the landscape, their sizes and proximity to one another, and the types of edge that define them.

Figure 6

Changes in a wooded area of Cadiz Township, Green County, Wisconsin, during the period of Euro-American settlement. The shaded areas represent land remaining in, or reverting to, forest. This fragmented landscape is likely to exhibit effects from changes in the amount of edge, reduced size of fragments, and isolation of fragments. From Curtis (1956) with permission of the University of Chicago Press.



1831 **1882** **1902** **1950**

and land clearing and conversion continue to contribute to fragmentation in both the north and the south. Some traditional resource management practices have also contributed to fragmentation.

Many species continue to do well in these artificially segmented landscapes. Some, such as white-tailed deer, are even more successful than they were historically. However, many species of plants and animals lose ground as a result of increased fragmentation. Fragmentation generally results in three types of change: fragment size reduction, increased isolation of fragments, and increased edge-to-interior ratios (Fig. 6).

Size Effects

As the size of a particular fragment becomes smaller and smaller, more and more species disappear from it. For example, very large blocks of prairie historically contained more than 400 vascular plant species and a multitude of animal species including microfauna, insects, herptiles, birds, and mammals. As the prairies were broken up, large ungulates such as bison and large predators such as wolves quickly disappeared. As fragmentation continued, some plant species disappeared and many others became rare. Now many are in serious decline.

The *size effects* of fragmentation are particularly noticeable in the southern and west-central two-thirds of the state. Here major ecosystems (grasslands, savannas, and southern forest) were reduced in size and severely fragmented by agriculture and by urban and rural residential development. Many remnants of these once-expansive ecosystems are represented by community fragments too small to support viable populations of many species. For example, most species of the grassland bird guild are in decline, as are reptiles and amphibians. The ornate box turtle requires a minimum of 250 acres of prime sand barrens habitat to sustain a viable population, but only three or four areas of this habitat size and quality remain.

In the north, communities and ecosystems historically dependent on fire, e.g., the oak and pine barrens, have been fragmented and diminished in size by forest encroachment. Populations of species such as sharp-tailed grouse, which depend on these open areas, continue to decline across their historic range due to loss of barrens and other open habitat.

Isolation

Isolation of habitat patches occurs as the landscape becomes progressively fragmented. Areas of the same type become isolated, not only by distance but by hostile intervening environment, putting plants and animals without adaptations for long-range movement at a severe disadvantage. The inability of a species to move between habitat patches leads to loss of genetic viability and diversity and can ultimately lead to elimination of that species within that fragmented habitat. As the intervening environment becomes increasingly hostile even the more mobile species have their movement between habitat islands thwarted. Today, many community and ecosystem fragments are so far apart and so reduced in size that many animals fail to maintain populations. The communities become closed systems subject to catastrophic change from events such as disease, drought, wind storm, or floods.

Some of the most prominent examples of isolation resulting from habitat or community fragmentation can be found in what is left of the prairie ecosystem. This ecosystem is now severely reduced to small isolated fragments scattered about in a "sea" of agricultural and other lands inhospitable to many of the prairie species, especially invertebrates and plants. Recent survey work in Illinois suggests that at least 15% of what is left of prairie insects are now restricted to prairie remnants. These remnants range in size from two to 1,000 acres; most are in the 2-40 acres in size. As much as 30%-40% of our prairie plants may also be remnant-restricted. Without connecting corridors or "stepping-stones" of close enough proximity and large enough size, many of these species populations will remain permanently isolated and thus subject to inbreeding, continued decline in numbers, and eventual elimination from that patch of habitat.

Aquatic ecosystems are also subject to isolation. All of Wisconsin's large rivers, most of its medium-sized rivers, and many smaller streams have been fragmented by dams. Fragmentation causes streams to become a series of modified ecosystems which no longer represent the native ecosystem in structure, function, and composition. Lake shores have also been fragmented by sand blankets and vegetation removal associated with shoreline developments. Dams prevent fish from reaching upstream spawning grounds, but there are other, more subtle effects of dams. For example, damming frequently isolates mollusks from the fish that host their larval stages; mollusks unable to complete their life cycle because of this isolation are eventually eliminated from the stream. For other species, populations are diminished when individuals succumb to siltation and other effects of damming.

Edge Effects

Edge effects occur near the interface of two or more different habitat types. Edge effects are beneficial for many plant and animal species, since edge allows them to take advantage of two or more habitat types for their survival. However, many other species are negatively affected by too much edge. The concentration of many species near edges causes increased competition, predation, and parasitism. For example, waterfowl nesting near the edges of grassy fields experience high nest predation, as do some songbirds nesting near forest-field edges. Or, some plants may disappear from previously suitable interior habitat when a new edge changes the micro-climate. As community or ecosystem islands get smaller or more disturbed, they become less and less viable for interior plants and animals. In effect they become all edge.

Encroachment of exotic species is closely associated with edge dynamics. In forests, many exotics gain entry to interiors by first getting established in the disturbance zone associated with human-caused disruption. Interior edge, which is more common in the north, is caused by logging, agriculture, blowdowns from wind storms, fire, and residential and commercial development, and takes on the same form and effect as exterior edge. Area- and edge-sensitive interior species are especially vulnerable to interior edge conditions.

Corridors for roads, power transmission lines, and pipelines create linear edge throughout the north, while in the south, these corridors sometimes bisect woodlots, wetlands, and grasslands. These corridors are havens for edge species and allow for penetration of species into otherwise continuous communities and ecosystems.

Environmental Pollution

Environmental pollution is the human-induced addition of many types of substances to air, land, and water in quantities and/or at rates that harm organisms, habitats, communities, ecosystems, or human health. Examples are nutrients, heavy metals, organic compounds, and sediments. Pollution may change the physical, chemical, or biological characteristics of air, water, or land, thus affecting the health, survival, or activities of living organisms in a variety of detrimental ways, including impacts on genetic, species, community, and ecosystem diversity.

Pollution may change the physical, chemical, or biological characteristics of air, water, or land—affecting the health, survival, or activities of organisms and contributing to the forces that simplify and fragment communities and ecosystems.

Any Department policies relating to biological diversity need to consider the effects of pollution and the efforts required to manage resources that have been adversely affected by pollution. The following examples illustrate some of these effects as they relate to water, air, and land resources.

Adverse Impacts to Surface and Ground Water Systems

Poorly managed construction sites and bare fields allow soil to wash off the land in runoff. This sediment can smother gravel riffles in a stream, destroying the habitat for aquatic invertebrates and spawning sites for some fish. Excessive organic waste flowing into a lake or stream uses up dissolved oxygen as it decays, which can kill aquatic life either through direct toxicity, destruction of habitat or food supplies, or by elimination of the dissolved oxygen needed by aquatic plants and animals. Phosphorus and other nutrients flowing off fertilized lawns and cropland into waterways may allow growth of excess algae and other aquatic plants. When large amounts of this vegetation die, decomposing bacteria use up dissolved oxygen, killing fish and other aquatic life.

Direct discharge of industrial effluent and sewage, which contain organic residues, chemicals, and sediments, can limit dissolved oxygen in the receiving water, otherwise change water chemistry, alter habitat, and kill organisms. Some chemicals present in industrial and municipal effluent, such as dioxin, have been shown to cause diseases, suppress the immune systems of a variety of species, harm reproductive capability, and produce genetic defects in offspring. The temperature of wastewater may also change normal aquatic temperature gradients and disrupt the life cycles of some aquatic plants and animals.

Pollution of ground water, caused by events such as gasoline leaking from underground storage tanks, nutrients leaching from inadequate septic systems, or pesticides washing off farm fields, poses a direct human health hazard when it reaches household water supplies. Contaminated ground water can also flow into streams and lakes, creating the same pollution effects as effluent that has directly entered surface water.

Adverse Impacts from Air-Carried Pollutants

There is increasing evidence that chronic exposure to certain levels of air pollution impedes the long-term survival and vigor of many species of plants. Trees in heavily polluted urban areas, for example, have a much shorter life span than trees of the same species in less polluted areas. In fact, some species of trees simply cannot grow in areas with severe air pollution. For example, high levels of ozone in the air of southeastern Wisconsin are known to limit the growth of several species of trees. Even at moderate levels of air pollution, some individuals within a population are genetically more sensitive to air pollution and will be eliminated from the population, resulting in simplification of the gene pool. This is a good example of reduction in genetic diversity. Neither the short-term nor the long-term implications of this simplification is understood at this time.

Acid deposition from air-carried pollutants may change water chemistry in some lakes, which in turn can change the diversity and abundance of aquatic organisms and communities. Acid deposition may change the pH of a waterbody, which can encourage the release of mercury already present in sediments or substrates. This process may enhance bioaccumulation of mercury, which accumulates in organisms at the top of the aquatic food chain, affecting their health, survival, or offspring.

There is limited but increasing evidence that mammals, birds, and other organisms are also adversely affected by inhaling airborne pollutants such as pesticides, heavy metals, and organic chemicals. If not directly toxic within an adult organism's life span, these substances may be toxic to an organism's progeny by causing birth defects, depressing the immune system, or changing the structure of DNA.

On a global scale, a build-up of carbon dioxide in the atmosphere from fossil fuel combustion may eventually affect climate and dramatically change ecosystems by causing global warming. Also, the release of chlorofluorocarbons and similar chemicals also depletes the ozone layer in the earth's stratosphere, thus exposing living things to harmful levels of ultraviolet radiation with potentially dangerous global implications.

Adverse Impacts to Land-Based Systems

Many land-based activities fragment or simplify ecosystems through pollution, either by direct effects such as an oil spill or through secondary impacts such as soil erosion from poor farming practices. Spills of hazardous materials can affect local areas by smothering animals or interfering with their movement. Improper disposal of hazardous wastes can result in local concentrations of metals or organic compounds that harm organisms and ecosystems. Pesticides and herbicides can kill nontarget species, changing the species composition in the area and weakening the ecosystems in which these organisms lived.

Land-based pollution also impacts other systems, most often surface and ground water systems. For example, an improperly functioning landfill may contaminate nearby soil and harm plants and animals living in the immediate area. However, leachate from the same landfill may also enter the ground water and contaminate lakes and streams miles away.

Implications of Ecological Issues

Our current understanding of ecosystems and, specifically, the implications of ecological simplification, fragmentation, and pollution present considerable opportunities and challenges to the Department's management programs. Present-day management strategies consider biological diversity mostly in a peripheral sense. Although awareness is increasing, overall program planning is not consistently based on the principles of ecosystem management. It is these principles that will allow us to address biodiversity within the context of ecological, socio-economic, and institutional concerns. These principles and their application to Department programs are fully discussed in the next section, "Addressing Biodiversity through Ecosystem Management."

While the main implication of the ecological issues is the need to implement ecosystem management, there are a number of related implications that are important to identify. First, staff will need the tools to determine the appropriate spatial and temporal scales as they plan and conduct their management activities. In the past, we have been most comfortable managing individual DNR properties on a short time frame (ten years or less), a scale at which we are able to observe immediate and obvious impacts, obtain the most information, and provide the most certainty. In the future, we will be managing at a larger scale, considering entire landscapes and much longer time frames, with less obvious immediate impacts.

One important tool that will help us think and plan on the landscape scale will be the delineation of *ecoregions*. Ecoregions are large areas of the state that exhibit similar patterns in potential natural communities, soils, hydrologic conditions, landforms, lithology, climate, and natural processes. Ecoregions provide a focus for resource assessment and inventory of biotic and abiotic elements. We need to determine the most useful boundaries for ecoregions within the state, and develop goals and management strategies for them. These will give us the framework needed to choose our priorities and focus our resources on carefully selected programs and projects.

We will also need data management techniques such as computerized *Geographic Information Systems* (*GIS*) to compile information on ecosystems and landscapes and to design process-oriented management approaches. These and other tools, such as a statewide aquatic and terrestrial inventory, will help us collect and manage the extensive amount of information needed to make decisions at a landscape scale.

The issues of ecological simplification, fragmentation, and pollution are not distinct issues that can be debated or weighed in isolation from each other. Like ecosystems themselves, these issues are often interrelated and complex. Ecosystem management focuses on evaluating the cumulative impact of proposed actions at the landscape level. At the same time, fragmentation and simplification may not always be bad. For example, the creation of edge between habitats to enhance populations of game species is desirable in certain locations within the landscape. The important thing is to recognize the complex impacts of our proposed actions (how much edge is desired and where should it be?), to clarify why they are desirable, to know the trade-offs, and to try to understand their impacts on ecosystem sustainability and, especially, on our options for the future.

Because our understanding of the ecological issues is constantly increasing, we can use our current understanding to make decisions to implement now and then adapt as we learn more. One approach that we will need to explore is currently known as *adaptive management*. Adaptive management considers many alternate management scenarios developed collaboratively by scientists, managers, and policy makers. Models are then developed to predict the results from each management alternative, management prescriptions are subsequently chosen, and monitoring programs are designed to scientifically test whether the management alternative does indeed accomplish the predicted results. In this way, the management practice enhances the "institutional memory" that documents our decision-making process while continually improving the science base for our management practices and advancing our knowledge of ecosystem functions.

Because the focus of this report is on the management of public lands, we do not propose specific recommendations for how the Department's regulatory programs might change to address the conservation of biodiversity. However, because pollution can seriously affect the biodiversity of a variety of aquatic and terrestrial communities, in the long run we must consider how the science of biodiversity can be incorporated into the regulatory and technical assistance work of DNR's environmental quality programs.

This report proposes that the best way to address biodiversity as a management issue is to apply the principles of ecosystem management to Department planning and programs. Ecosystem management is a system to assess, conserve, protect, and restore the composition, structure, and function of ecosystems, to ensure their sustainability across a range of temporal and spatial scales, and to provide desired ecological conditions, economic products, and social benefits.

Addressing Biodiversity Through Ecosystem Management

What is Ecosystem Management?

To understand what the conservation of biodiversity will mean to the Department's management system, we must understand ecosystem management as the philosophy and process we will be using in the future. *Ecosystem management* is a system to assess, conserve, protect, and restore the composition, structure, and function of ecosystems, to ensure their sustainability across a range of temporal and spatial scales and to provide desired ecological conditions, economic products, and social benefits.

The above definition reflects the complexity that the ecosystem management "umbrella" is meant to encompass. What does it really mean? In simpler terms, ecosystem management blends human needs and values with ecosystem capability and sustainability (Fig. 7). This blending of multiple perspectives is essential to making wise choices about how resources will be managed to result in an agreed-upon pattern of land uses. This pattern will be a mosaic of cities, towns, and suburbs; parks, lakes, wetlands, and forests; farms and industries; natural areas and reserves; and corridors and riverways.

The landscape pattern that is desired will be defined over time as we work with multiple interests and partners in decision-making. This report proposes that we make a commitment to the **principles and processes** of ecosystem management and fully develop within that commitment the goals and criteria that will be needed to conserve biodiversity as an essential element of ecosystem sustainability.

In listing these principles and processes, it may be helpful to think of them in the following two categories: Ecosystem Approaches and Critical Thinking Skills.

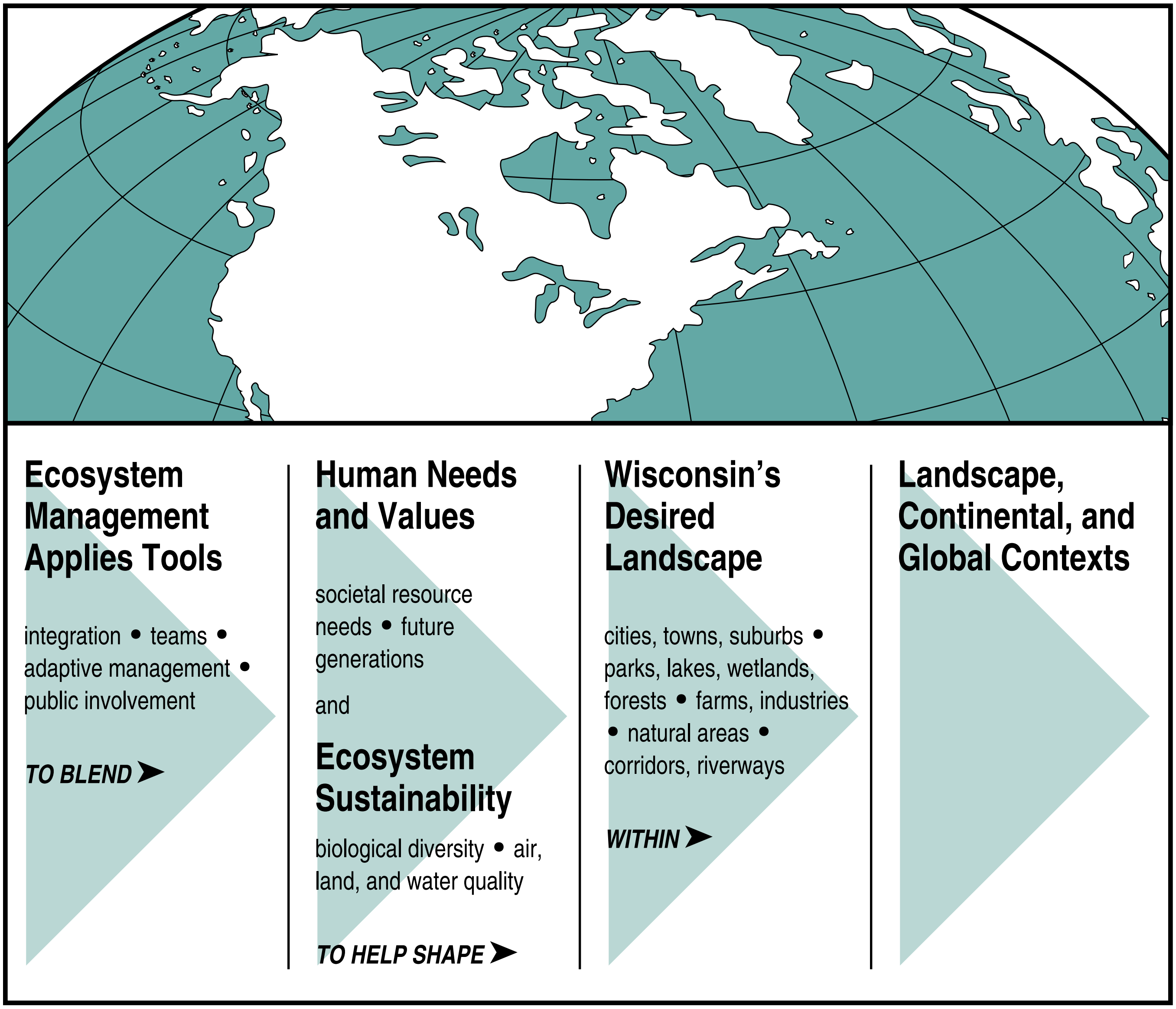


Figure 7

The processes and components of ecosystem management.

Ecosystem Approaches

Management goals should be set and action taken using an ecosystem management approach that integrates staff and resources across programs and disciplines. Current statutory charges were developed to manage single species or small assemblages of economically important species. However, biological diversity is not, and should not be treated as, a separate organizational subprogram. Rather it will be included within the entire range of issues that DNR managers must consider when they carry out the agency mission.

- ▲ **Determine ecoregion boundaries and use them to develop management goals.** Set goals within ecoregions to meet a wide variety of diverse ecological and socio-economic needs, including the conservation of biodiversity.

- ▲ **Manage to preserve ecological composition, structure, and function.** Consider not only immediate impacts but also the dynamics of long-term changes induced by proposed management actions.

- ▲ **Manage at a landscape scale.** Determine both spatial and temporal scales appropriate to a problem or project. Assess the impacts of decisions made at any one scale on both smaller and larger scales.

- **Incorporate a *transdisciplinary perspective*.** Develop and support a diverse staff with a working knowledge of a wide range of disciplines and a willingness to integrate those disciplines in innovative ways. New ways of working together will transcend the limitations posed by traditionally separate disciplines. Managers working in integrated teams will form the foundation for the way we "do" ecosystem management.

- **Find ways to take action without "knowing all the answers."** Use a management approach that can be applied now while allowing us to continually increase our understanding of ecosystems and adapt our practices as we learn more. Used within an ecosystem management approach, the adaptive management approach described earlier can help us do this in a formal and structured way.

Critical Thinking Skills

Employees and the public must be encouraged to take responsibility for examining their own knowledge and beliefs. Commitments to solutions that treat problems, not just symptoms must also be encouraged. This will require that we foster *critical thinking* skills. Critical thinking is a process of reflection and analysis that involves the identification of assumptions and known facts, the exploration of alternatives, and the integration of new understandings into thought and behavior patterns. For example, in order to support critical thinking, we must:

- **Provide DNR employees and the public with training and awareness opportunities.** Prepare staff to lead the public dialogue that will produce a clear and widely accepted understanding of biodiversity and decisions that we can collectively support and implement in our day-to-day living.

- **Lead the discussion clarifying public values related to biodiversity and the environment.** Continue to bring diverse interests together to discuss and resolve the issues. Work to anticipate problems, manage conflict, and avoid the kinds of confrontations between conflicting interests that have occurred in other states.

- **Act on a vision of biodiversity that is grounded in scientific fact, clarified values, and hard-nosed realism.** View projects that aim to conserve biodiversity with the same scientific rigor that we view those to develop the landscape for other human needs. Be responsive to the role that values play in exploring alternative solutions to problems and in selecting final approaches.

We won't be able to implement all of the recommendations and possible actions in this report at once. We will need to set realistic priorities and clear course of action that provides a roadmap for DNR staff and our partners and clients.

Using Ecosystem Management Routinely

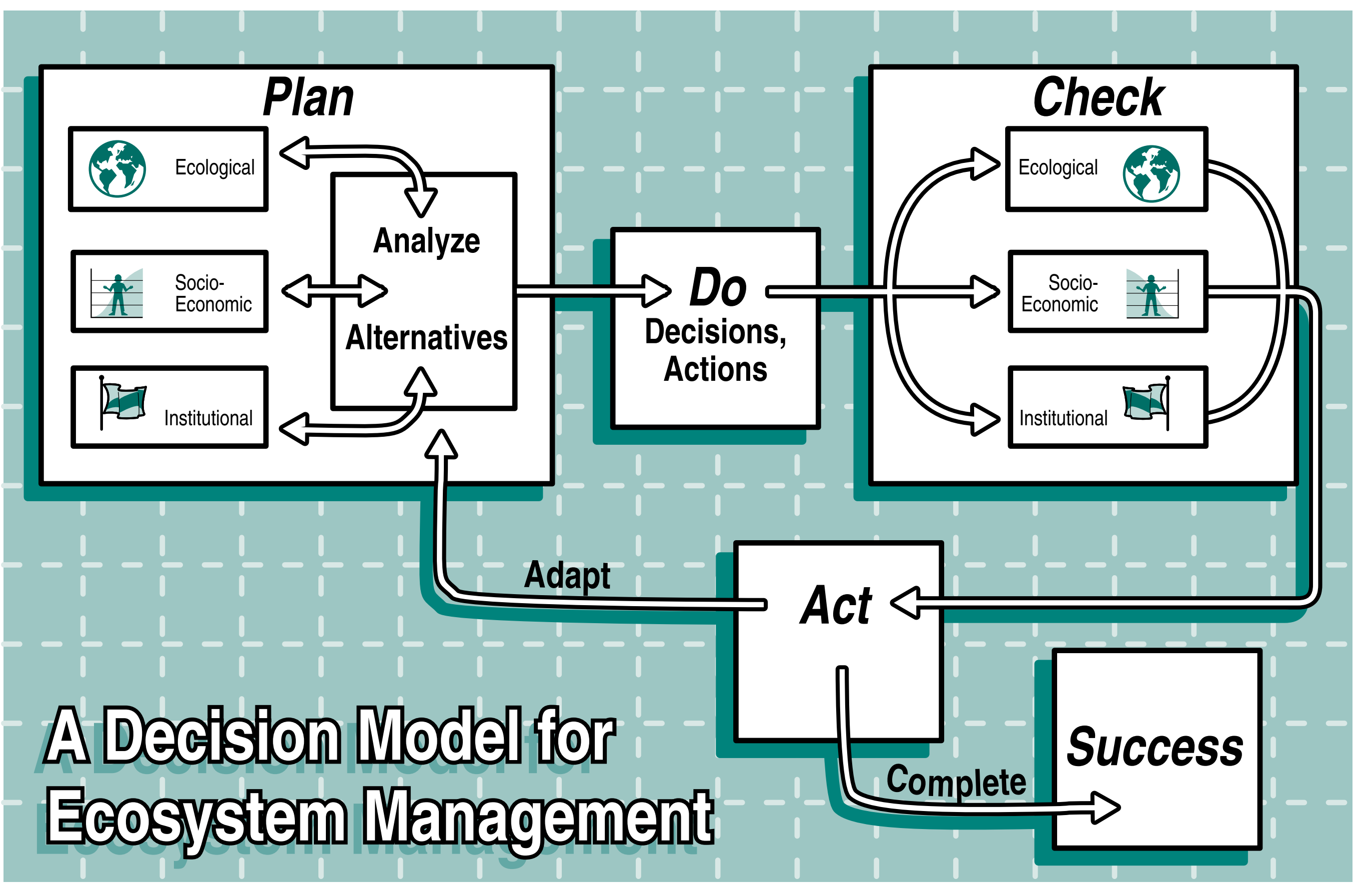
We will be expected to apply the principles of ecosystem management on a daily basis. Some aspects of ecosystem management are familiar to DNR managers, many of whom have been thinking in terms of ecosystems and integrated approaches for many years. Many of the procedures required to conserve biodiversity are already included in our "toolboxes," and others need to be invented. Whether the ideas are familiar or new, all managers will have questions about how to use ecosystem management principles in daily work and how to meld these comprehensive management approaches with traditional management activities. They will ask questions like: "How much restoration can we do?," "How should we view active management practices like fish-stocking and clearcutting?," "How can we reconcile biodiversity with user demands?," "How does ecosystem management consider the needs of humans as well as the needs of all other species?" The answer to each question depends on the specific circumstances or context in which it is asked. For example, a decision to restore a damaged community is appropriate in some situations but inappropriate (or impossible) in others. Similarly, a decision to stock fish may fulfill a user demand at the expense of native species, or it may replace a missing predator and restore balance to a lake's ecosystem. The appropriateness of any management practice or environmental decision depends on its context. There are no easy answers or "cookbook" formulas for management practices that will always conserve biodiversity. Rather, we must use a management model that brings perspectives and knowledge from different disciplines together in an integrated search for alternatives.

The ecosystem management decision model shown in Figure 8 provides a framework that requires us to approach decision-making from different perspectives. By examining several alternatives relative to their consequences in ecological, socio-economic, and institutional contexts in the PLAN phase, the model holds that we will make wiser management decisions. Whatever alternative we decide to implement (DO) is then monitored (CHECKED) for its actual results in all three contexts, and we revise our management (ACT) according to those results. Our success as resource stewards is a function of our ability to understand, analyze, and integrate alternatives across all three of these contexts.

The ecosystem management decision model presents a structured approach to the search for solutions that integrate ecological, socio-economic, and institutional concerns.

Figure 8

An ecosystem management decision model.



The Ecosystem Management Decision Model

The ecosystem management decision model is based on an examination of questions and considerations within each of three contexts: the ecological, socio-economic, and instituional:

The Ecological Context

Defining and subsequently managing in an ecological context is both an art and a science. As our understanding of ecological concepts grows, as our body of ecological theory and scientific evidence is enriched through time, and as our measures of the impact of various decisions on the ecosystem become more predictable and precise, our ability to identify and make informed ecological choices will increase.

Depending on the ecosystem and the management issue, a variety of considerations are used to establish the ecological context. The process of determining the ecological context begins with a definition of scale, followed by an assessment of the system's *capability* and function.

Scale

Question: *At what spatial and temporal scales should the decision be defined?*

Some considerations:

✓ size of the affected system and its parts
✓ current inventory of what is there now, including measures of biological diversity
✓ species with critical needs or special status
✓ presence of ecological gradients and corridors
✓ patterns of community distribution
✓ existing patterns of disturbance or change
✓ current management practices, land use, and land ownership

Capability

Question: *What is the system's past, current and potential future ecological capability; where is the landscape headed?*

Some considerations:

✓ natural and potential capability (e.g., presettlement vegetation as one indicator)
✓ history of successional stages
✓ potential for recovery, enhancement, or expansion
✓ potential to be self-sustaining

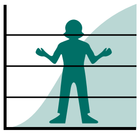
Function

Question: *How can we improve or protect the system's function? How well is it working now?*

Some considerations:

✓ interrelationships between the abiotic and biotic components—missing components (composition, structure)
✓ connectivity
✓ fragmentation
✓ resilience
✓ gene flow
✓ energy and nutrient flow
✓ food webs

THE SOCIO-ECONOMIC CONTEXT



The Department also manages in a socio-economic context that reflects the varied and sometimes conflicting needs and values of people. Our mission requires us to be responsive to society, yet it recognizes that our decisions also help to shape society's values. Furthermore, our actions have direct impacts on the economy at the local and state levels, and beyond. Our decisions are evaluated within this socio-economic context, and society determines our success or failure. As we work with stakeholders to understand their views and values, we also need to understand the impact of management activities on local business, land values, and other economic factors, including a view of long-term economic perspectives.

We can understand the socio-economic context by knowing the stakeholders and the range of economic issues they represent.

SCALE

Question: *At what spatial and temporal scale should the decision be defined? What is the magnitude of social and economic effects?*

Some considerations:

✓ number of people affected, directly and indirectly
✓ cost and funding for the project
✓ time period for completion
✓ time period of social or economic impacts
✓ scope of social or economic impacts (local, state, regional, national, international)

LAND USE

Question: *What are the past, present, and potential land uses?*

Some considerations:

✓ current and previous land uses
✓ projected changes in land uses
✓ alternative future land uses
✓ indirect effects on adjacent or regional land uses
✓ land ownership patterns

ECONOMIC IMPACTS

Question: *What are the opportunities and threats for business and employment?*

Some considerations:

✓ direct and indirect impacts on local and state businesses
✓ potential new businesses created
✓ impact on current and projected property values
✓ impact on employment
✓ sources of raw materials or other resources for business
✓ relationship to transportation or utility networks
✓ relationship to national and international economy

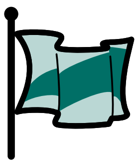
STAKEHOLDER INTERESTS

Question: *Who are the stakeholders and how can they best be involved? What are their various perspectives, needs, and values?*

Some considerations:

✓ major and minor stakeholders (public and private)
✓ role of elected officials
✓ public involvement and information strategies
✓ relationship of stakeholders to DNR and to each other
✓ opportunities for partnerships with stakeholders

THE INSTITUTIONAL CONTEXT



As an institution, the Department operates within a matrix of complex institutional relationships. First, the Department's actions must be based on sound legal authority. This authority is defined by state constitution, state and federal statutes, administrative rules, and court decisions. Second, Department actions are also affected by internal policies and by budgets, staffing, and various authorities granted to the agency. Management actions that do not fit within this external or internal institutional framework or authority are either not feasible or require changes in our laws, codes, or mission. And third, the Department has many opportunities to create cooperative agreements and partnerships with other public and private institutions, as well as with individuals, in order to meet mutual goals for resource protection, restoration, or enhancement.

LEGAL FRAMEWORK

Question: *What institutional support or constraints come from outside DNR? What is DNR's legal relationship to local, state, and federal governments?*

Some considerations:

✓ legal authority (statutes and administrative rules)
✓ legal constraints
✓ processes for obtaining decisions from appropriate authority (local government, legislature, federal agencies)
✓ need for new legal authorities or changes in existing laws
✓ state budget development, federal grants, etc.

INTERNAL DNR POLICIES:

Question: *What internal policies or procedures support or hinder a proposed action?*

Some considerations:

✓ strategic plans
✓ budget and staffing
✓ manual codes and handbooks

INTERAGENCY COOPERATION AND PRIVATE PARTNERSHIPS

Question: *What kinds of relationships with other public agencies or with private interests are needed?*

Some considerations:

✓ existing and potential partners and cooperators
✓ institutional constraints of partners and cooperators, such as their ability to enter into long-term agreements
✓ innovative approaches to cooperation and partnership

Is this model all that new? Many parts of the model are not new, in that they represent the way many managers have thought and acted for years. The Department has conducted a number of planning efforts that are based on watersheds or other ecological units and have dealt with a range of socio-economic and institutional issues. Examples are the Green Bay Remedial Action Plan, the Winnebago Pool Integrated Resource Management Plan, the Milwaukee River Integrated Resource Management Plan, and the Mississippi River Strategic Plan. There are other examples cited as case studies within the following chapters on Wisconsin's biological communities. These include projects related to the Baraboo Hills, Marathon County Forest, Habitat Restoration Area (formerly Glacial HRA), Southern Unit Kettle Moraine State Forest, and Patrick Lake wetland mitigation.

What is new is putting all the parts together and using them throughout the Department as a decision framework. Also new is the importance of considering multiple levels of scale in all decisions. While some managers already do this, we need to work together to do it consistently, with attention to all contexts of the ecosystem-management decision model.

Success lies in carefully considering all three context—ecological, socio-economic, and institutional—and finding an alternative that is acceptable in all three. We cannot only consider the ecological context in making management decisions. The "correct" ecological decision may be impossible or unworkable given the realities of our society, the economy, and the institutions in which we work. Similarly, the "best" economic decision may be ecologically disastrous. Our hope is to provide an open public process in which social, economic, and ecological perspectives are evaluated and weighed early on—before positions become hard and fast. It is, in reality, a search for acceptable alternatives that help preserve long-term options and improve the quality of our everyday lives and the lives of the generations to come.

Recommendations

Implementing ecosystem management in Wisconsin requires concrete actions. The following recommendations are the product of review by and dialogue with internal DNR staff and external partner agencies, scientists, interest groups, and citizens. The recommendations are put forth to begin the process of working with the Natural Resources Board and all our partners and customers to outline the details of specific actions needed. As we move forward, we will need much more discussion, both internally and with the public.

1 ***Apply ecosystem management principles and practices to the Department's programs so that goals and priorities for biodiversity can be determined in the context of ecological, socio-economic, and institutional issues.***

- Use the ecosystem management decision model, as described in this report, to propose and evaluate alternative actions from the ecological, socio-economic, and institutional perspectives.

- Develop and use ecoregion goals and objectives to design and implement geographically-based management guidelines. These procedures will provide the criteria needed for:

  - ✓ land acquisition priorities
  - ✓ new and revised master plans for state-owned property
  - ✓ priorities for restoration of biological communities
  - ✓ use of appropriate genotypes in restoration and management
  - ✓ management of populations of troublesome non-native species
  - ✓ goals for consumptive use, such as harvest of forest products, fish, and wildlife

- Continue to develop a Geographic Information System (GIS) as a major management tool needed to implement ecosystem management and to establish and evaluate ecoregion goals and objectives. Train staff to use GIS to analyze and monitor regional landscapes.

- Continue to develop and use a statewide resource inventory of the status and distribution of aquatic and terrestrial species, biological communities, and other attributes within the ecoregions of Wisconsin.

- Use the biennial budget guidance to address management priorities and goals for ecosystem management.

- Review existing laws and procedures to analyze their consistency with the principles of ecosystem management. Modify them where necessary. This will be a formidable task, since our procedures are embodied in a multitude of handbooks and guidelines. However, these procedures must be consistent and must work for, not against, ecosystem management and the conservation of biological diversity.

- Monitor and respond to ecological, socio-economic and institutional issues as they develop. Examples of current issues that arise in the ecological context include the role our management actions may play in ongoing fragmentation and simplification, the need for prescribed burning as a management tool, and the desire to manage for the range of successional stages of each major community type.

- Employ both research and experimental management to develop new management approaches and to refine existing ones. These efforts should be directed at expanding our understanding of ecosystems and clarifying options for future management.

2 ***Build partnerships with other agencies, local governments, tribes, the business community, scientists, and other interest groups to accomplish common goals for ecosystem management, including specific attention to biodiversity.***

- Seek innovative ways to work with partners to set landscape-scale goals that cross ownership boundaries.

- Continue to participate in joint efforts such as the 1994 Wisconsin Forest Accord (a memorandum of understanding to adopt uniform criteria to describe, evaluate, and share critical ecological information among private landowners and nonprofit, county, state, and federal agencies) and the Interagency Cooperation on Ecosystem Management or ICEM (a multi-agency resolution forming a consortium of 20 Midwestern state and federal agencies, including Wisconsin's DNR, working together to coordinate ecosystem management activities).

- Take advantage of the knowledge and capability of the scientific community in reviewing how we apply scientific knowledge to our management strategies.

- Seek input from business and economic interests to develop strategies to implement ecosystem management.

- Work with hunting and fishing groups to use the principles of ecosystem management to improve the quality of hunting and fishing in Wisconsin.

- Encourage and support efforts at the national level to screen proposed introductions of non-native species.

3 ***Build partnerships with private landowners to accomplish common goals for ecosystem management, recognizing that the Department cannot accomplish the breadth of what needs to be done to conserve biodiversity by working on public lands alone.***

- Establish coalitions and partnerships with private landowners to protect and restore biological diversity.

- Provide technical assistance, economic incentives, and education to encourage private landowners to participate in the conservation of biological diversity.

4 ***Develop innovative and proactive information and education strategies for Department staff and the public regarding biodiversity and its relation to ecosystem management.***

- Create ecosystem management demonstration areas in each ecoregion that invite hands-on participation and illustrate applied ecosystem management and biodiversity concepts.

- Design approaches to outreach and training to increase understanding of ecosystem management and to clarify the variety of professional and personal values regarding biodiversity.

- Provide support to employees to increase their skill in bringing diverse groups of people together to discuss and resolve issues related to ecosystem management and biodiversity.

5 ***Set priorities for implementing the possible actions specific to each of Wisconsin's seven biological community types described and assessed in the remaining chapters of this report.*** These possible actions are described in detail at the end of each of the seven biological community chapters. We call these "possible actions" because they are consistent with ecosystem management but require more analysis and planning. The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

CHAPTER 3

Overview of Wisconsin's Biological Communities

by Betty Les
Bureau of Endangered Resources
Department of Natural Resources

The location and extent of plant communities and the animals associated with them are determined by environmental gradients of moisture, temperature, soil type, and climate. They are also shaped by historical events, migration, and natural and human-induced disturbance.

Determinants of Biodiversity

The location and extent of plant communities and the animals associated with them are determined by environmental gradients of moisture, temperature, soil type, and climate. They are also shaped by historical events, migration, and natural and human-induced disturbance. The most pronounced environmental gradient in Wisconsin is located in a narrow band that runs from northwestern to southeastern Wisconsin. This band has been termed the tension zone (Fig. 9). Many species of plants and animals reach the limit of their ranges in this zone. In Wisconsin, the tension zone delineates the northern forest, including the boreal element, from the southern forest and prairies. Although climate is a major reason for the tension zone, soil type and other factors also play a role.

Impact of Glaciation

The greatest historical event impacting Wisconsin vegetation occurred 10,000-60,000 years ago when Wisconsin was invaded by continental ice sheets. These glaciers transformed Wisconsin's landforms and vegetation. Vegetation was scoured away and mountains were planed down in all except the southwestern region of the state, leaving a rolling plain covered by a layer of glacial till. Remnants of Wisconsin's earlier topography are visible in hard rock outcrops such as Rib Mountain and the Baraboo Hills. Each interglacial period, including the present one, was revegetated through migration, which occurred through range extension and seed dispersal to favorable habitats. Migrants originated from communities centered as far away as the Ozarks, Pennsylvania, Texas and other areas. Some of the tree species now in Wisconsin had glacial refuges in the southern Appalachians and the eastern coastal plain. Although only a portion of species were able to perpetuate themselves over the long term, what is now Wisconsin regained tremendous floristic diversity through migration and colonization following glaciation. An additional component of floristic diversity is derived from the relict species occurring in the Driftless Area of southwestern Wisconsin. These species pre-date glacial activity and often exist nowhere else in the state.

The glaciers also had a tremendous influence on Wisconsin surface waters. Glacial deposits dammed rivers and scoured out lakebeds creating large water bodies such as the Great Lakes and Lake Winnebago. Some small water bodies were created by the numerous pits or depressions in the glacial till, which filled with groundwater. In the north, most are found in sandy, pitted outwash and were formed when buried ice blocks melted after retreat of the glacial ice. The nature of these aquatic features was determined, in large part, by their landscape position. For example, the landscape position of lakes in the groundwater and surface flow system determined their basic water chemistry.

Basic water chemistry, in turn, influenced and continues to influence the sensitivity of waters to eutrophication and such present-day concerns as mercury toxicity and acid rain. Landscape position has also influenced the species present in a given lake because it determines how connected that particular lake is to other lakes and sources of colonization. Thus, the glaciers created a template, or backdrop, on which present-day waters have developed.

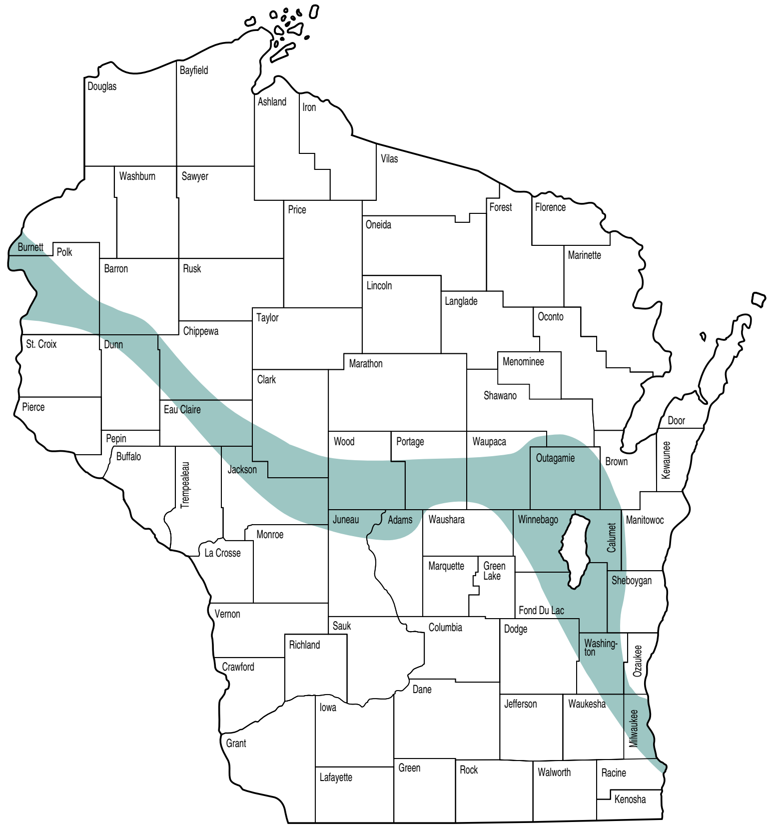


Figure 9

Location of the tension zone, adapted from Curtis (1959).

Impact of Other Natural Disturbance

Other types of natural disturbance have also influenced Wisconsin plant and animal communities. Chief among these have been windstorms, lightning-induced fire, and droughts, which were often a factor in severe fires. Floods have also influenced the natural communities, but to a lesser degree. Historically, all of these factors individually and in combination have impacted the landscape. Climate and temperature changes have greatly influenced the significance of these disturbances.

Windstorms frequently produced disturbance that varied in significance from a local to landscape scale. A recent example of this is on the Flambeau River State Forest, where much of the old growth was destroyed in a minimum of five different windstorms between 1949 and 1977. The most significant of these storms occurred in the downburst of 1977, when hundreds of thousands of acres across the state were disturbed. A much earlier example of climatic influence occurred during the warming period that followed the last glaciation. Floodwater from the melting glacier probably created extensive floodplains and terraces in south-central Wisconsin. The presence of prairie species in the pollen record of this period, plus an increase in charcoal, indicates an interspersion of dry periods and fire. The frequency, combination, and size of these disturbances continues to influence the mosaic of the natural communities.

> The greatest historical event impacting Wisconsin vegetation occurred 10,000-60,000 years ago when Wisconsin was invaded by continental ice sheets. These glaciers transformed Wisconsin's landforms and vegetation. Vegetation was scoured away and mountains were planed down in all except the southwestern region of the state, leaving a rolling plain covered by a layer of glacial till . . . . The glaciers also had a tremendous influence on Wisconsin surface waters.

Human-Induced Disturbance

Human-induced disturbance had a profound impact on Wisconsin plant and animal communities, exceeded only by the impact of glaciation. For centuries before Euro-American settlement, Native Americans lived in the area now known as

Although the landscape was affected as Native Americans used resources and interacted with the land, changes reflected a level of human use many times less intensive than present-day use. Urbanization, highway construction, and the host of other developments associated with modern life have produced tremendous changes in Wisconsin's landscape.

Wisconsin. Although the size of their populations and the extent to which they used the land are undocumented, both are probably far greater than once thought. Scientists estimate North American populations at 3.8 million or more at the time of European contact (Denevan 1992). The Wisconsin region no doubt supported large Native American populations due to its abundant natural resources.

Fire was one of the Native Americans' primary tools for managing these resources. Fire was used to concentrate game for hunting, increase game habitat, and clear paths for travel. Also, natural fires went largely unsuppressed. The result was development of extensive communities—prairies, savannas, barrens, and oak woodlands—that were fire-dependent and, in fact, a product of fire. Approximately 40%-45% of Wisconsin's land surface was covered by these fire-dependent communities prior to Euro-American settlement (Curtis 1959). The more mesic northern and southern forests were fire resistant, but their composition and structure were probably altered to some extent through intentional management by Native American populations.

The nature of the plant communities prior to European contact is unknown, although scientists continue to piece together a description based on the record left by pollen, sediment, and explorers' journals. The first systematic record of Wisconsin's vegetation communities was created in the mid-1800s, when the U.S. Geological Survey's land survey of Wisconsin was completed. This was some 350 years after contact, well after disease introduced by European explorers had decimated Native American populations. Vegetation maps based on the land survey records show a diversity of natural communities including extensive forests and wetlands plus the fire-dependent grassland, barrens, and savanna communities (Fig. 10). These communities are commonly referred to as Wisconsin's *presettlement* vegetation. This convention was adopted for our report.

Euro-American settlement marked the beginning of a simplification of Wisconsin's landscape and a decrease in biodiversity. In the absence of fire, the prairie, savanna, barrens, and oak woodland communities gradually filled in with shrubs and trees. When settlers realized the depth and richness of the prairie and savanna soils, these areas were cleared for agriculture and grazing, leaving only traces of the original plant communities. Forested areas were either cleared for farming or cut for timber as the need for building material surged at the turn of the century. Except for pockets of forest, northern Wisconsin was completely cut over. Slash timber left on the ground fueled unnaturally severe fires that further denuded the land and at times damaged the soil. The forest was slow to regenerate itself, and when it did, it was very different from the earlier forests.

Although the landscape was altered as Native Americans used resources and interacted with the land, changes reflected a level of human use many times less intensive than present-day use. Urbanization, highway construction, and the host of other developments associated with modern life have produced tremendous changes in Wisconsin's landscape. Fragmentation and simplification of plant communities and pollution have accompanied these changes. Impacts of these disturbances are discussed in more detail in the "Ecological Issues" section of this report.

Nineteenth century land surveying, a pen drawing from the collections of the State Historical Society of Wisconsin. *Illustration courtesy of Kenneth Lange.*

The Situation Today

Today, Wisconsin has forest cover roughly equal to that in place at Euro-American settlement, but it is very different in age structure and species composition. Barrens, savannas, and grasslands exist but only in scattered locations. *Postglacial* lakes and rivers have remained relatively constant in number and surface area, but we have lost about one-half of our wetlands along with the seasonal ponds associated with them. Most of what we have left of prairies, savannas, and certain wetlands (e.g., sedge meadows) is the result of managed use of fire, since these community types are fire-dependent.

> Today's remaining biological communities provide valuable sources of genetic and species diversity. Our challenge is to retain the range of diversity still present and, where possible, regain diversity through restoration.

Thus, today Wisconsin still has a great deal of biological diversity, but it has also lost a great deal of diversity (Fig. 11). All of today's communities provide valuable sources of genetic and species diversity. Our challenge is to retain the range of diversity still present and, where possible, regain diversity through restoration. In going about this work, we must strive to measure diversity in ways other than *species richness*. Understanding and measuring diversity at a functional level will put us in a better position to predict the impact of various actions on plant and animal communities.

The following sections of this report profile Wisconsin's seven major biological communities:

- northern forests
- southern forests
- oak and pine barrens
- oak savannas
- grasslands
- wetlands
- aquatic systems

These seven communities represent an aggregation of the more numerous communities described by Curtis (1959) (Table 1). Curtis' system of classifying vegetation was chosen as the framework for this report because it was designed specifically for Wisconsin and has stood the test of time. Recent interest in biodiversity and ecosystem management has spurred the development of a number of regional and national systems for classifying communities and ecosystems. One such system, the National Hierarchy of Ecological Units, has been adopted by the Department's Division of Resource Management as the standard for its work (U.S. Dep. Agriculture 1993). The Curtis system and others such as Kotar et al. (1988) will nest within this hierarchy, which is designed to stratify the Earth into progressively smaller areas of increasingly uniform ecological potentials. Thus, it can be used at multiple geographic scales ranging from a single site in our state to an area that spans several states or the entire nation. Maps depicting ecoregions and various other ecological units will be developed to assist in setting management goals and objectives.

In this report, each of the aggregated communities is described and compared to its presettlement status (for an overview of how rare each of the communities has become, see the global ranks in Table 1). After status, actions causing concerns and socio-economic issues related to conservation of each community are discussed, and the potential for restoring the community to a sustainable, functional state is assessed. Finally, possible actions are listed for managing and restoring each community. Note that some of Curtis's communities are discussed in more than one of the aggregated communities due to overlap in composition, structure, or function. Although the communities are categorized

Table 1. Wisconsin plant communities. Compiled by R. Henderson based on Curtis (1959) and the Wisconsin Natural Heritage Inventory.

Aggregations Used in this Report	Curtis (1959) Communities and their Global Rank*	Aggregations Used in this Report	Curtis (1959) Communities and their Global Rank*
Northern Forest	Boreal Forest (*G3*) Northern Dry Forest (*G3*) Northern Dry-Mesic Forest (G4) Northern Mesic Forest (G4) Northern Wet-Mesic Forest (*G3*) Northern Wet Forest[+] (G4)	Grassland	Bracken-Grassland (G3) Sand Barrens Dry Prairie (G3) Sand Prairie** Dry Lime Prairie** Dry-Mesic Prairie (G3) Mesic Prairie (G2) Wet-Mesic Prairie (G2) Wet Prairie[+] (G3) Calcareous Fen[+] (G3) Southern Sedge Meadow[+] (*G3*) Northern Sedge Meadow[+] (G4)
Southern Forest	Southern Dry Forest (G4) Dry Oak Woodland** Southern Dry-Mesic Forest (G4) Mesic Oak Woodland** Southern Mesic Forest (*G3*) Southern Wet-Mesic Forest Southern Wet Forest[+]	Aquatic	Emergent Aquatic (G4) Submergent Aquatic Lake Beach
Oak Savanna	Oak Opening (G1) Dry Oak Opening** Dry-Mesic Oak Opening** Mesic Oak Opening** Wet-Mesic Oak Opening Wet Oak Opening** Cedar Glade	Wetland	Open Bog (G4) Alder Thicket (G4) Shrub Carr Northern Wet Forest (G4) Southern Wet Forest Wet Prairie (G3) Calcareous Fen (G3) Southern Sedge Meadow (G3) Northern Sedge Meadow (G4)
Oak/Pine Barren	Oak Barrens (*G2*) Pine Barrens (G3)	Minor Misc. (not covered in the report)	Exposed Cliff Shaded Cliff Lake Dune

* Rank reflects global rarity. Community classification is not standardized for the nation. Thus, not all of the communities have ranks, and some of the ranks had to be adapted to Wisconsin communities based on criteria for similar communities elsewhere. Also, some relatively low-ranked forest communities may be rare in some seral stages (i.e., specific occurrences of the community may be highly ranked). Ranks appearing in italics are considered tentative at this time.

G1 = Critically imperiled globally because of extreme rarity (5 or fewer occurrences or very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction.

G2 = Imperiled globally because of rarity (6 to 20 occurrences or few remaining individuals or acres) or because of some factor(s) making it very vulnerable to extinction throughout its range.

G3 = Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g., a single state or physiographic region) or because of other factors making it vulnerable to extinction throughout its range; in terms of occurrences, in the range of 21 to 100.

G4 = Apparently globally secure, though it may be quite rare in parts of its range, especially at the periphery.

G5 = Demonstrably secure globally, though it may be quite rare in parts of its range, especially at the periphery.

** Postulated communities. Due to their rarity, these communities cannot be rigorously quantified at this time.

[+] Also covered to some extent in the Wetland Communities.

Figure 10 (overleaf)

Vegetation cover of Wisconsin in the mid-1800s, compiled from U.S. General Land Office Notes by Robert W. Finley, 1976.

This map is based on the original land survey of Wisconsin carried out in the mid-1800s by the U.S. General Land Office. The purpose of the original survey was to establish the township-range-section grid for Wisconsin. For each section and quarter-section point, nearby trees were selected as bearing trees and their diameters and distances from the corner were recorded. In treeless areas, the crew built a mound of earth at the corner point and recorded that the point was in an open area. Surveyors were also required to describe the timber and agricultural value of the land, its topography, and water bodies and to provide a general description and map for each township (Lange, 1990).

These records were used by Robert W. Finley of the University of Wisconsin Extension to reconstruct the vegetation patterns present at the time of the survey. Dr. Finley completed his work in 1976. This map and others like it are useful in helping people visualize the general location, extent, and diversity of vegetation present in the last century.

Finley's map was originally designed and prepared by the Cartographic Laboratory, University of Wisconsin-Madison and was subsequently digitized by the University. The digital version presented in this report was further modified and enhanced by staff of the Department's Bureau of Information Management, GEO Services Section.

Figure 10

Vegetation cover of Wisconsin in the mid-1800s, compiled from U.S. General Land Office Notes by Robert W. Finley, 1976.

Figure 11

Land use and land cover for Wisconsin, compiled from high-altitude aerial photography taken from 1971-81.

Figure 11 (overleaf)

Land use and land cover for Wisconsin, compiled from high-altitude aerial photography taken from 1971-81.

This map is based on data from the U.S. Geological Survey Land Use Data Analysis Program. Data were interpreted from 1:58,000 scale color infrared and 1:80,000 panchromatic aerial photography from the National High Altitude Photography Program. Photographs were acquired in the years 1971-81.

The map is useful in helping people visualize the current land cover for Wisconsin and for assessing the magnitude of change over the past 100+ years. Although this map and the companion map on mid-1800s vegetation cover (Fig. 10) are based on very different types of data and technology, broad comparisons of cover types during the two time periods can be made.

Figure 11 was produced by the Bureau of Information Management, GEO Services Section.

according to the plants they support, the faunal element of each community is also discussed to the extent possible with existing information. Some of the most numerous and functionally important animal groups (e.g., insects) are the least documented or understood. Thus, animal coverage is inadequate but points the way for future work.

In discussing restoration, it is important to note that we do not envision restoring communities to conditions prior to Euro-American settlement. This would clearly be an unrealistic goal. The presettlement status of each community is an important indicator of site potential and serves primarily as a guide and benchmark in our restoration efforts. Our desired state is a more diverse landscape, considering all four levels of diversity (genetic, species, community, and ecosystem level) across all land uses.

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CHAPTER 4

Northern Forest Communities

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Description

> The term northern forest, as applied in Wisconsin, is primarily a geographic designation and does not in itself imply any specific species composition . . . . It may be characterized as a region of mixed deciduous and coniferous forests occurring north of the tension zone.

The term *northern forest*, as applied in Wisconsin, is primarily a geographic designation and does not in itself imply any specific species composition. In broad terms, it may be characterized as a region of mixed deciduous and coniferous forests that represent one of the two distinct climatic zones in Wisconsin as separated by a loosely defined S-shaped transition belt known as the "tension zone." The region north of this zone is generally called the northern forest (see Fig. 9).

Forest communities, present and historic, display considerable diversity in composition of dominant species. About 30 tree species occur in the northern forest as a whole, although fewer than ten are usually found in any given community, with dominance generally being shared by only two of three. Throughout the region, mature stands on the medium to rich soils (loams and silt loams) are dominated by various mixtures of five or six principal species: sugar maple, basswood, hemlock, yellow birch, white ash, and American beech. Red oak and red maple are the most common minor associates. In presettlement times, white pine was also a common associate in these northern hardwood forests. The poorer soils (sands and loamy sands) are generally dominated by mixtures of pines (jack, red, and white), aspen, white birch, red maple, and red oak. Extensive wetland forests are also common to this region. These can be divided into two basic types: conifer swamps (black spruce/tamarack and white cedar) and hardwood swamps (black ash, red maple, and elm).

These broadly described forest types, based upon dominant vegetation, only begin to reflect the total biological diversity of forest communities of the region. A system of ecological classification of forest communities and sites on which they occur is necessary. Such a system has been developed for forests in northern Wisconsin (Kotar et al. 1988) (Table 2) and will be completed for the rest of the state by 1994.

Status

Past

Post-Glacial Environment

The entire area of present-day northern forest has been affected by Pleistocene glaciation. Several major glaciations and countless minor ice advances and recessions have created a complex pattern of ice and meltwater-influenced deposits. Some of these deposits were subsequently covered by wind-blown silty or loamy material called loess. This tremendously complex array of deposits formed the parent material from which present soils have developed and are, in fact, still in the process of development. Although soil scientists recognize several hundred soil classes

Curtis (1959) Communities	Kotar et al. (1988) Habitat Types
Northern Dry Forest	*Acer-Quercus/Vaccinium* *Quercus-Acer/Epigaea* *Quercus/Gaultheria-Ceanothus*
Northern Dry-Mesic Forest	*Pinus/Maianthemum-Vaccinium* *Pinus/Amphicarpa* *Quercus/Amphicarpa* *Acer/Vaccinium-Desmodium* *Acer/Vaccinium-Viburnum* *Acer-Quercus/Viburnum* *Acer/Athyrium*
Northern Mesic Forest	*Acer/Viola-Osmorhiza* *Acer/Hydrophyllum* *Acer/Caulophyllum-Circaea* *Acer-Tsuga/Dryopteris* *Acer-Fagus/Dryopteris* *Acer-Tsuga/Maianthemum*
Northern Wet-Mesic Forest	*Tsuga/Maianthemum-Coptis*

Table 2

An ecological classification system for the northern forest.

The dominant vegetation of the northern forest only begins to reflect the total biological diversity of the region.

within the region of the northern forest, the present soils can be grouped into four broad categories based on the mode of glacial deposition of parent material. These are:

- Ground moraines or till plains, consisting of assorted material including boulders, gravel, and sand but usually also containing considerable amounts of silt and clay. Soils developed from till are usually the most productive.

- End moraines and recessional moraines. These deposits are also composed of till, but are usually coarser textured than are ground moraines, and they form more rugged topography. The resulting soils are somewhat droughtier and have lower nutrient content than do soils derived from ground moraines.

- Pitted outwash. These meltwater-deposited sands and gravels contain depressions (pits) that often have steep slopes and may be filled with water. Several large areas in northern Wisconsin are dominated by this type of landform (e.g., Burnett, Washburn, Vilas, and Oneida counties).

- Outwash plains and terraces. These deposits are similar to those of the pitted outwash, often sandier than pitted outwash, but the terrain is flat or only gently sloping. Unless modified by a blanket of loess, pitted outwashes and outwash plains form the droughtiest and least fertile soils of the region.

These four basic types of glacial deposits form a moisture-nutrient gradient, which is the strongest factor controlling the establishment of invading plant species. Plants themselves exert considerable influence on soil development. Even

The northern forest landscape. We see a matrix of forest with aquatic features imbedded. The continuous forest is a mosaic of old-growth stands of hemlock (Plum-Star Lakes Hemlocks State Natural Area is between the lakes), wildlife openings, and adjacent stands that have been harvested (foreground). *Photo by Michael J. Mossman.*

though the original parent material has been modified to varying degrees since the last glaciation (10,000 to 60,000 years ago, depending on location), the distinctions due to parent material persist.

Present community composition is the result of environmental influence (soil and climate) and various historical factors. It is not meaningful to speak of "original vegetation" without reference to some specific time period. Many plant species found in Wisconsin today may have been present before the Pleistocene, but not necessarily in present locations and in present combinations. Paleoecologists have determined that present Wisconsin vegetation consists of elements from three distinct floristic provinces: the Boreal, the Prairie, and the Alleghenian (Hulten 1937, Cain 1944). Members of the Alleghenian province are more or less distributed throughout the southern and northern forests, while the boreal species are more prevalent in the northern half of the state and prairie species more prevalent in the southern half.

There is evidence that many species are still extending their ranges; consequently, floristic stability on the geologic scale may not be reached for some time even if the climate remains stable. This fact is often overlooked, especially in North America where the presettlement condition of the vegetation is often presumed to have been in a relatively static climax state. This change, however, is so slow that most of the changes seen in the past 150 years can be attributed to the influences of Euro-American settlement.

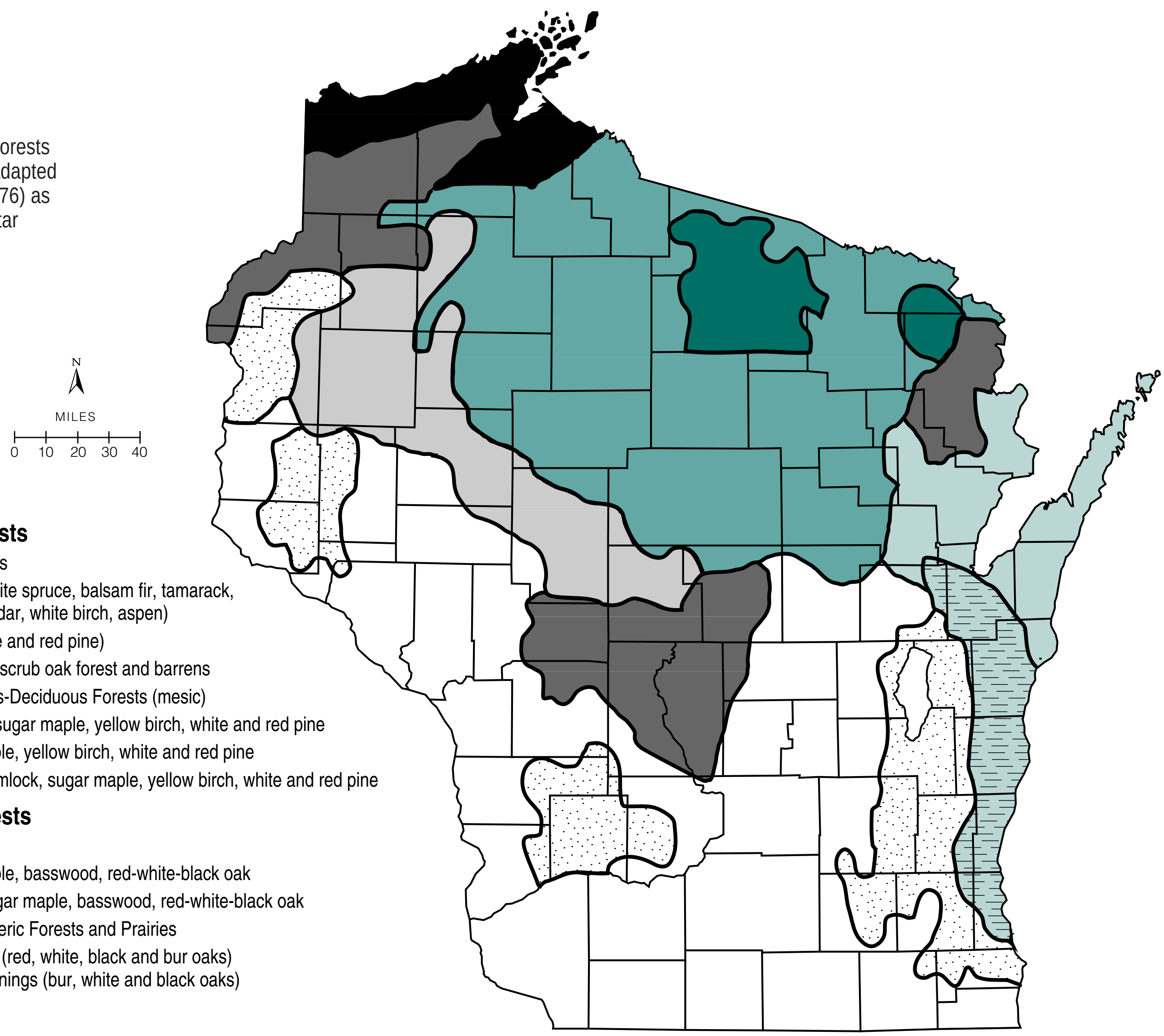


Figure 12

Presettlement forests of Wisconsin, adapted from Finley (1976) as modified by Kotar (1990).

Northern Forests

Mainly Coniferous

- Boreal (white spruce, balsam fir, tamarack, white cedar, white birch, aspen)
- Pine (white and red pine)
- Jack pine, scrub oak forest and barrens

Mixed Coniferous-Deciduous Forests (mesic)

- Hemlock, sugar maple, yellow birch, white and red pine
- Sugar maple, yellow birch, white and red pine
- Beech, hemlock, sugar maple, yellow birch, white and red pine

Southern Forests

Mesic

- Sugar maple, basswood, red-white-black oak
- Beech, sugar maple, basswood, red-white-black oak

Dry-mesic and Xeric Forests and Prairies

- Oak forest (red, white, black and bur oaks) Oak openings (bur, white and black oaks)

Composition of Presettlement Forests

The exact nature of the floristic and structural composition and the geographic variation of the northern forest in presettlement times has never been described, and it probably will never be known with certainty. However, descriptions and occurrences of prominent forest types, at least in terms of tree species composition, were recorded by numerous early observers (e.g., Knapp 1871, Chamberlin 1877, Warden 1881). These early observers had already recognized the tension zone, without using the term, and consistently described four to six forest types occurring north of the zone: (1) pine forests, composed of white pine and red pine mixtures with no hardwoods; (2) mixtures of hemlock, sugar maple, and yellow birch, with, to the east, beech and large white pine; (3) scrub pines and scrub oaks; (4) hardwoods without conifers—mainly sugar maple, yellow birch, basswood and sometimes a mixture of red oak and white oak; (5) swamp forests composed of spruce, fir, tamarack, and white cedar; and (6) oak openings or savanna (only south of the tension zone).

The exact floristic and structural composition of the northern forest in presettlement times has never been described, and it probably will never be known with certainty.

The best information on the composition of the northern forest during the earliest period of Euro-American settlement comes from the records of the rectangular survey of public lands (General Land Office Surveys). These surveys contain a systematic record of the kinds and sizes of trees used as witnesses for lines and corners, as well as more or less detailed accounts of vegetational changes encountered. Finley (1976) produced a map of the presettlement vegetation of Wisconsin based on survey records contained in 671 volumes of surveyor notebooks. These records describe 54,000 square-mile sections and 110,000 linear miles of traverse. Although surveyors did not record forest communities—they only identified individual trees—Finley constructed abstract communities based on dominant tree species. He organized the data into 11 forest community types, seven of which represent the upland forests of northern Wisconsin. Figure 12 is a redrawn and simplified version of Finley's large and complex map. It shows the primary distribution of the six major forest types of northern Wisconsin plus three southern forest types. Numerous scattered fragments of depicted types were deleted. The six northern forest types are described as follows:

1. **Boreal forest—**white spruce, balsam fir, tamarack, white cedar, white birch, aspen. This forest type occurred in a limited area of the extreme northern part of the state, near Lake Superior. Most ecologists today agree that this community type, although resembling the boreal forests of Canada, is a distinct geographic variant of its northern namesake.

2. **Pine forest—**dominated by white pine and red pine. Contrary to the common belief that most of northern Wisconsin was covered by extensive pure stands of white pine and red pine, this forest was extremely limited even before Euro-American settlement. The most extensive block occurred in Vilas and Oneida counties.

3. **Jack pine, scrub oak forests, and barrens**. This is a loosely described type characterized by mixtures of poor-quality trees or poorly stocked stands of jack pine, pin oak or bur oak, or sometimes red oak. Mixtures of red pine and white pine, red maple, aspen, and white birch were often included. Figure 12 shows three principal areas of occurrence: Washburn, Burnett, and Douglas

counties in the northwest; Marinette County in the northeast; and Juneau, Adams, and Jackson counties in the central part of the state.

4. **Hemlock, sugar maple, and yellow birch, with mixtures of white pine and red pine**. This was the largest and perhaps the most characteristic forest formation in northern Wisconsin. It is also sometimes referred to as the "hemlock-northern hardwood" or simply the "northern hardwood" forest.

5. **Sugar maple and yellow birch, with a mixture of red pine and white pine**. This type represents the southern and western transition of the preceding type. Absence of hemlock, which reaches the western limit of its natural range in these regions, is its main characteristic. Although this community designation may appear arbitrary, the abrupt termination of the range of hemlock, a species which is ubiquitous eastward to the Atlantic coast, suggests a significant climatic shift.

6. **Beech, hemlock, sugar maple, and yellow birch, with a mixture of red pine and white pine**. American beech is another tree species that reaches the western limit of its range in Wisconsin. Just as in the case of hemlock, climatic influence is presumed to control the range of beech, although the role of calcareous soils, climate, and incomplete post-Pleistocene migration have been suggested as additional factors (Davis et al. 1986).

Factors Controlling the Dynamics of Presettlement Forests

Before we examine the present status of the northern forest complex, we must consider the factors controlling the composition and perpetuation of presettlement forests. Simply because present forest communities are known to be largely the result of human-caused disturbances, it does not follow that presettlement forests were unaffected by perturbation and were stable and in balance with regional climate. Of the six presettlement forest types described above, none can be explained without invoking some form of environmental disturbance. The three northern hardwood types (4, 5, and 6 above) could presumably self-perpetuate without the aid of disturbance, because sugar maple, hemlock, beech, and to some degree yellow birch are shade tolerant. However, the presence of shade-intolerant white pine and especially red pine in these communities could not be explained without a disturbance factor.

Simply because present forest communities are known to be largely the result of human-caused disturbances, it does not follow that presettlement forests were unaffected by perturbation and were stable and in balance with regional climate.

Although fires occurred less frequently in mesic hardwood stands than they did in coniferous forests, many fire-scarred trees and stumps predating the logging era were observed by early surveyors. However, severe and extensive fires were probably not very common in northern Wisconsin. The main evidence for this is a very low occurrence of aspen and birch stands among presettlement forests. In the Lake States, such stands are almost always associated with fires. Finley's map shows only widely scattered, small patches of this type and almost none within the northern hardwood-pine regions. There is also evidence that extensive windthrows in hardwood stands were even more common. Often the majority of stumps from old-growth pines are found on mounds or knolls in stands that have a characteristic kettle-knoll microtopography caused by the uprooting action of winds. In fact, numerous studies have shown that disturbances have been occurring in somewhat cyclic fashion in all terrestrial ecosystems (Heinselman 1973, Lorimer et al. 1988).

Climax and Old Growth

Much unnecessary confusion exists today regarding these two terms. The concept of climax vegetation and in fact the entire concept of succession, as originally defined by Clements and other early 20th century ecologists, have been seriously questioned in recent years (Christensen and

Peet 1984, Christensen 1987). Community development after a disturbance leads toward a more or less definable *climax community* controlled by regional climate (climatic climax). However, in many areas, due to topographic or soil influences, a regionally uniform climatic climax cannot be attained, except perhaps on a geologic time scale. Such terms as “topographic,” “edaphic,” or “topoedaphic climax” are commonly used to refer to the presumed “terminal” communities on such sites. Thus, in northern Wisconsin the climatic climax of sugar maple, hemlock, and beech can be expected only on more mesic, nutrient-rich soils. The droughtier and less fertile sandy soils simply do not support these demanding species; instead these soils are colonized by a number of shade-intolerant or pioneer species. Because all of the pioneer species on sandy soils are shade-intolerant, they are incapable of replacing themselves through advance regeneration, as is the case with mesic forest species. Which, if any, species can be considered to represent the edaphic climax on the poorest soils is still not clear. Perhaps the answer to this question is only of academic interest; sooner or later a disturbance inevitably initiates a new cycle.

“*Old growth*” is a much simpler concept than is climax vegetation. In some cases old growth may also be climax (e.g., a 300-year-old sugar maple—hemlock community without a mixture of white pine), but most often it is simply a community with dominant trees at or near biological maturity (Table 3). However, studies show that very old stands possess ecological properties that differ significantly from those of immature stands of the same floristic composition (Lorimer and Frelich 1992). However, although old growth appears to provide optimal habitat for some species of plants and animals, to date no vertebrate species have been shown to be obligate inhabitants of old growth. Thus, the old-growth ecosystems may best be thought of as structural and functional parts of larger landscapes. However, most studies have focused on vertebrate species and vascular plants. Habitat needs of invertebrates and lower plants in relation to old growth are largely unknown. The alliance *Lobarion pulmonaria*, an association of rare lichens, grows primarily in old-growth forests of northern hardwoods (Thompson 1990).

Old-growth ecosystems may best be thought of as structural and functional parts of larger landscapes.

The early survey records suggest that presettlement forests consisted of a mixture of young, mature, and old forests. Old forests were common in many areas, but successional processes were evident (Lorimer and Frelich 1992).

Old-growth community of yellow birch and hemlock. A recent tip-up creates gap and allows light to release sugar maple seedlings. *Photo by Michael J. Mossman.*

Table 3

Generalized age characteristics of old growth. Precise age varies with site-specific conditions. Based on representative sites in north-central Wisconsin. *Compiled by R. Eckstein.*

	Age (years)		
Cover Type	**Old Growth Begins**	**Cover Type Deteriorates**	**Individual Tree Longevity**
Aspen	60	80	150
Northern red oak	100	160	250
White/red pine	130	200	400
Northern hardwood	150	—	350
Hemlock-yellow birch	150	—	500

Old-growth pine forest. An old tip-up creates the coarse, woody debris characteristic of old-growth pine communities. Dunn Lake Pines State Natural Area. *Photo by Signe Holtz.*

The Logging and Euro-American Settlement Era

Between the mid-1800s and early 1900s Wisconsin forests were almost entirely cut over. The impact of logging and associated activities was widespread and varied. Space here does not permit a comprehensive treatment of the ecological consequences. Only those factors most responsible for the differences between presettlement and current forest conditions are highlighted.

Early logging concentrated on white pine and, to some degree, on red pine. Scattered trees as well as pure stands were harvested wherever they were found. This had the immediate impact of virtually eliminating the white pine seed source from the northern hardwood complex. Because slash was burned intentionally or unintentionally, most of the reproduction was also eliminated. Hemlock was removed in a later wave of logging when the tanning industry, which used hemlock bark, was developed.

The stump of an old, large white pine (>36" dbh) within an even-aged stand of young sugar maples. *Photo by Michael J. Mossman.*

Hardwoods were harvested last, after railroads and, later, logging roads were built. Both clearcutting and high-grading (i.e., cutting only the most valuable trees) were practiced. Because most hardwoods have less stringent requirements for germination and seedling establishment than do the pines and hemlock, and in addition possess sprouting ability, species such as sugar maple, beech, basswood, yellow birch, and ash were seldom eliminated from a site unless there were repeated fires. However, the species composition of new stands was often severely altered. High-grading consistently favored sugar maple and beech, whereas clearcutting usually resulted in more mixed stands.

A large portion of presettlement forest was later cleared for agriculture. Many cleared lands proved unsuitable for farming and were abandoned. This was especially true for areas with sandier soils that originally supported conifers. Many of these lands were later planted back to trees, but often without regard for site potential and species compatibility. The successful farming that remains in northern Wisconsin is largely confined to sites formerly occupied by high-quality mesic hardwoods.

Present

Vegetation

Both the species composition and relative proportion of presettlement forest types have been greatly altered by humans. The mixed coniferous-deciduous types have, with a few exceptions (e.g., the Menominee Indian Reservation), lost their coniferous component. Hemlock occurs sporadically in second-growth hardwood stands, but white pine is virtually absent in many areas and shows no signs of regeneration, even where suitable seedbed is created by natural or human-caused disturbance. The necessary supply of seed simply does not exist.

The relative importance of hardwood species has also changed significantly in many stands. While sugar maple has retained its dominant position, yellow birch is much less common than it once was. On the other hand, basswood and white ash are now usually the most important associates of sugar maple, although they were seldom listed as such by early surveyors.

Most of the presettlement white pine forests (pure or mixed with red pine) are today occupied by mixtures of red oak, red maple, white birch, and aspen, although white pine is showing a remarkable comeback in many areas.

By far the largest change has occurred in the distribution of the aspen-birch type. While scarcely present on Finley's map of presettlement vegetation, today it represents the largest single forest cover type in the state. Much of it extends over the landscape previously occupied by mesic hardwoods, indicating that the post-logging fires also occurred in these communities.

Considering the northern forest region as a whole, the overall species richness of plants and animals does not appear to be threatened. Probably few if any species of flora have been lost, although relative abundance of many has been greatly altered. Figure 13 shows the extent of the largely continuous northern forest in 1992. The northern forest includes parts of 19 counties. The total land area in forest cover ranges from 59% to 93% on a countywide basis.

Considering the northern forest region as a whole, the overall species richness of plants and animals does not appear to be threatened. Probably few if any species of flora have been lost, although relative abundance of many has been greatly altered.

There are 8.3 million acres of commercial forest land in the northern forest.[2] Public land totals 3.5 million acres and ranges from 17% to 56% of the total land in northern forest counties. The forest industry owns 987 thousand acres; forest industry land ranges from less than 1% to 25% of total land area in northern forest counties. Of commercial forest land, maple-birch makes up 31%, aspen 29%, elm-ash-soft- maple 7%, paper birch 5%, oak 5%, and balsam fir 5%.[3] White cedar, black spruce, white spruce, white pine, red pine, and jack pine forest types each make up less than 5% of commercial forest land. Non-stocked land makes up 1% of commercial forest land (Spencer et al. 1988).

The northern forest is characterized by a sapling and pole-sized forest. Seedlings-saplings range from 6% of commercial forest land in Menominee County to 38% of commercial forest land in Oneida

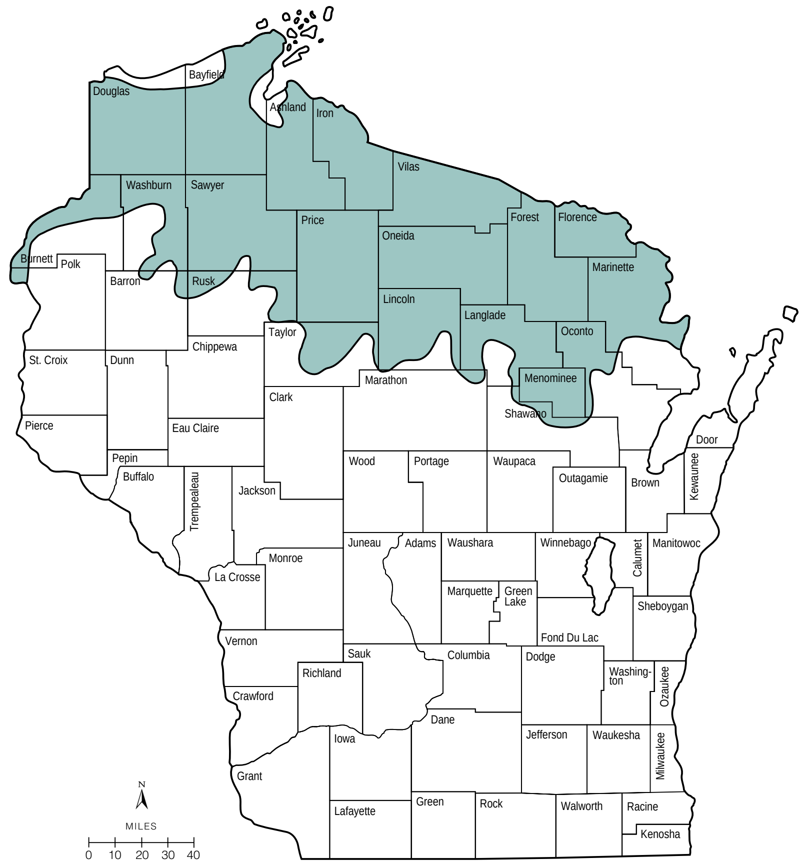


Figure 13

The continuous, extensive forest of northern Wisconsin, adapted from McCaffery and Creed (1969).

[2] Commercial land is defined as land producing or capable of producing crops of industrial wood and not withdrawn from timber production (Spencer et al. 1988).

[3] Maple-birch is a loosely labeled type that includes sugar maple, yellow birch, basswood, white ash, and hemlock.

County. Pole timber makes up 49% of commercial forest land. Sawtimber stands do not predominate. This reflects the continual rebuilding and maturation of stands from the cut-over and burned-over conditions at the turn of the century. It also reflects the domination of pole and small sawtimber-size material for timber products as the primary objective of forest management on several million acres of forest land. Sawtimber area and volume decreased from 1936 to 1956, then began increasing from 1956 to 1983 (Stone and Thorne 1961, Spencer and Thorne 1972, Smith 1986).

Pine plantations cover 355,000 acres in northern Wisconsin. Red pine makes up 61% of the total, and jack pine makes up 22% of the total (Smith 1986). Between 1956 and 1968, 500,000 acres were planted in all of Wisconsin. Most acres were planted to red pine (Spencer and Thorne 1972), but red pine was often inappropriate for the site. In addition, inferior genetic stock, row planting, furrowing, destruction of humus layer, and elimination of ground vegetation caused ecological problems.

The growing-stock volume of nearly every tree species increased between 1968 and 1983, except for elm, hemlock, and yellow birch, for which volumes declined. An average of 21.6 million board feet of hemlock and 14.7 million board feet of yellow birch were removed annually from commercial forest land in northern Wisconsin. These tree species exhibit very low regeneration rates (Raile 1985).

Between 1964 and 1983, 12% of commercial forest land was harvested. Of the 12% harvested, 72% had a partial cut and 28% was clearcut. All past and current logging practices change forest communities. In addition, introduced insects and diseases, such as dutch elm disease and white pine blister rust, have significantly altered the composition of post-settlement forests.

Table 4

Changes in the relative abundance and distribution of selected wildlife in Wisconsin's northern forests: 1850–1994. *Compiled by R. Eckstein.*

	Relative Abundance				Distribution			
Species	**Mid-1800s**	**Early 1900s**	**Mid-1900s**	**1994**	**Mid-1800s**	**Early 1900s**	**Mid-1900s**	**1994**
White-tailed deer	Low	Low	Abundant	Common	Clumpy	Clumpy	Continuous	Continuous
Coyote	Low	Common	Abundant	Common	Clumpy	Clumpy	Continuous	Continuous
Bobcat	Low	Low	Common	Rare	Clumpy	Clumpy	Continuous	Clumpy
Moose	Low	Rare	Gone	Rare	Clumpy	Isolated	Gone	Isolated
Snowshoe hare	Low	Common	Abundant	Low	Clumpy	Continuous	Continuous	Continuous
Timber wolf	Common	Common	Gone	Rare	Continuous	Continuous	Gone	Clumpy
Fisher	Common	Rare	Gone	Common	Continuous	Isolated	Gone	Continuous
Pine marten	Abundant	Rare	Gone	Rare	Continuous	Isolated	Gone	Isolated
Elk, wolverine	Low	Gone	Gone	Gone	Clumpy	Gone	Gone	Gone
Bald eagle, osprey	Common	Common	Low	Common	Common	Continuous	Clumpy	Continuous
Ruffed grouse	Low	Common	Abundant	Common	Clumpy	Continuous	Continuous	Continuous
Woodcock	Low	Common	Abundant	Common	Clumpy	Clumpy	Continuous	Clumpy
Sharp-tailed grouse	Low	Abundant	Common	Rare	Clumpy	Continuous	Clumpy	Isolated
Beaver	Common	Rare	Low	Abundant	Continuous	Isolated	Clumpy	Continuous
Grassland birds	Rare	Common	Common	Rare	Isolated	Continuous	Clumpy	Isolated
Interior forest birds	Abundant	Rare	Rare	Common	Common	Continuous	Clumpy	Continuous
Young-forest birds	Rare	Common	Common	Common	Isolated	Clumpy	Continuous	Continuous

Animals

Benyus et al. (1992) compiled a list of 389 vertebrate species present in the northern forests of Michigan, Minnesota, and Wisconsin. The list included birds (71%), mammals (17%), and reptiles/amphibians (12%). Fifty-three percent of these species were uncommon, 37% common, and 10% occasional. These species used all kinds of habitats in all successional stages. Of the forest species, 49% used mature forest and 40% used young forest. Thirty-three species were classified as highly versatile in habitat use, while 204 species had intermediate versatility and 152 species were restricted to specific habitats.

The distribution and abundance of animals in the northern forest have changed dramatically (Table 4). Among mammals, unregulated commercial hunting and trapping as well as dramatic habitat changes has resulted in extirpation of elk, wolverine, woodland caribou, Canada lynx, fisher, pine marten, moose, eastern cougar, and eastern timber wolf. In recent years fisher, pine marten, and eastern timber wolf have been reestablished, and eastern cougar and moose occur in very low numbers.

Lack of large blocks of wild land with low human presence limits populations of some animal species, e.g., eastern timber wolf (Thiel 1985), black bear, bobcat, moose, eastern cougar and spruce grouse. These species are known as extensive forest specialists. These are usually large, wide-ranging, or sensitive animals. The forest need not be mature and can be intensively managed. However, it must have low human presence.

Other mammal species dropped to very low numbers when logging and Euro-American settlement drastically altered their habitat, then increased as the forest began to mature again. These include gray squirrel, porcupine, flying squirrel, and beaver. Still other species, such as raccoon, striped skunk, woodchuck, thirteen-lined ground squirrel, and eastern cottontail, became much more abundant as young forests, edge, resorts, small towns, and agriculture provided favorable habitat. In recent years, despite maturing forests, badgers have become established in low numbers throughout the northern forest.

The fisher was once extirpated from the northern forest but has recovered after reintroduction. *DNR photo*

Presettlement white-tailed deer populations ranged from five to 15 deer per square mile (Dahlberg and Guettinger 1956, Habeck and Curtis 1959). Deer occurred at very low numbers between 1900 and 1915 but then began to increase (Swift 1946). Abundant favorable habitat caused populations of white-tailed deer and snowshoe hare to grow to very high numbers. Snowshoe hare populations peaked in the early 1930s and were again very high in the 1940s (Cunningham 1993). White-tailed deer populations peaked in the 1940s with 40 to 50 deer per square mile of deer range (Keith McCaffery, Dep. of Natural Resources, pers. comm.). These very high deer and hare populations caused widespread damage to vegetation.

Lack of large blocks of wild land with low human presence limits populations of some animal species.

Current Deer Management Unit population goals reflect current forest habitat conditions. Management Unit goals in the northern forest average 18 (range ten to 25) deer per square mile of deer range. Snowshoe hare populations are currently low because of widespread predation, particularly by fisher. The impact of white-tailed deer and snowshoe hare on the composition and structure of forests needs to be viewed on a broad temporal and spatial scale (Mladenhoff and Stearns 1993).

Many of the human and ecological forces that impacted mammal species also affected bird species. Habitat changes and unregulated commercial hunting extirpated the passenger pigeon from Wisconsin; the species became extinct in 1914. Although common in presettlement and early Euro-American settlement times in Wisconsin, bald eagles, osprey, and Cooper's hawks dropped to low numbers by the mid-1900s because of indiscriminate shooting and reproductive failure caused by pesticides. In the early 1900s, red-shouldered hawks declined as mature lowland deciduous forests declined. Extensive logging, fire, and scattered agriculture created favorable habitat for species such as sharp-tailed grouse, upland sandpiper, eastern bluebird, American goldfinch, golden-winged warbler, American crow, gray catbird, northern harrier, red-tailed hawk and American kestrel. These species are now declining as the forests have grown back and are maturing.

> Many of Wisconsin's amphibian and reptile species are found throughout the state, often in wetlands located within other vegetative communities. However, some species with highly specific habitat requirements are found only in the extensive northern forests .

Species that are adapted to young or disturbed forests have increased as this successional stage has increased. These species include ruffed grouse, woodcock, chestnut-sided warbler, mourning warbler, blue jay, rufous-sided towhee, brown thrasher, Nashville warbler, indigo bunting, rose-breasted grosbeak, and great horned owl.

One bird species, the brown-headed cowbird, has increased dramatically in the eastern United States and in southern Wisconsin. In agricultural areas this nest parasite can cause forest bird species to decline. In the northern forest, cowbirds are uncommon but present in local agricultural areas and near towns. In the forested environment, cowbirds are present in first-year aspen clearcuts, young conifer plantations, and large grassy openings. The impact of cowbirds on northern forest bird populations is unknown.

In the past, forest birds adapted to large blocks of mature forest decreased in numbers as these forests were converted to brushland. Examples include the barred owl, pine warbler, Blackburnian warbler, black-throated blue warbler, yellow-bellied sapsucker, pileated woodpecker, eastern wood-pewee, Swainson's thrush, wood thrush, solitary vireo, cerulean warbler, and scarlet tanager. The northern hardwood component of the northern forest is recovering (Stearns 1990) but occurs in smaller blocks (Mladenhoff et al. 1993). It now averages 70 years of age, is developing an all-aged structure, and again supports populations of mature forest birds (Hoffman 1989).

Forest practices can negatively affect some species of forest birds (Temple 1988, Howe et al. 1992). However, properly modified forest practices, in the context of the extensive northern forest, can enhance habitats for forest birds (Temple et al. 1979, Hoffman and Mossman 1990, DeGraaf et al. 1992, Probst et al. 1992, Thompson et al. 1992, DeGraaf et al. 1993, Thompson et al. 1993, Welsh and Healy 1993).

Forest ponds are breeding habitat for many species of frogs and salamanders. Abundant decaying logs on the forest floor as well as an uncompacted forest floor litter layer are important habitats for salamanders and invertebrates. Many of Wisconsin's amphibian and reptile species are found throughout the state, often in wetlands present within other vegetative communities. However, some species with highly specific habitat requirements are found only in the extensive northern forests (Vogt 1981). Examples are the mink frog, red-backed salamander, and spotted salamander. Other species such as the wood frog, northern red-bellied snake, and wood turtle are most common in the northern forest but occur elsewhere in Wisconsin as well. Because no thorough inventories have been conducted for Wisconsin's reptiles and amphibians, we have no basis to compare current distribution and abundance with that of the past.

Except for pest species, little research has been directed at forest invertebrates. Lack of knowledge in this area is a serious concern since invertebrates are a very diverse group and perform important ecosystem functions.

Threatened and Endangered Species

Threatened and endangered bird and mammal species that have a significant portion of their range in the northern forest include eastern timber wolf, Canada lynx, pine marten, bald eagle, osprey, red-shouldered hawk, and wood turtle. Threatened and endangered plants of the northern forest include moonwort, goblin fern, Smith melic grass, pine-drops, small shinleaf, foamflower, calypso orchid, ram's head lady's-slipper, small round-leaved orchid, Braun's holly fern, drooping sedge, auricled twayblade, broad-leaved twayblade, and hawthorn-leaved gooseberry.

Projected

Projections of future dynamics of Wisconsin's forests are difficult to make without a knowledge of future management or utilization objectives of a changing society. Barring major changes in forest ownership and resource utilization policies, the following trends can be expected:

- ▲ The total forested area will probably remain the same or increase slightly.

- ▲ The aspen-birch type will gradually decrease as forest succession progresses. The area in aspen has declined 1.8 million acres since 1936 (Spencer et al. 1988). Aspen stands today are perpetuated almost entirely by commercial clearcutting. Current utilization is not keeping up with the rapid maturation rate of this short-lived species.

- ▲ Portions of current aspen-birch type will be replaced by various mixtures of white pine, red maple, and occasionally red oak. A significant proportion will succeed to mixed stands of mesic hardwoods, with sugar maple playing the largest role.

- ▲ All forests currently dominated by mesic hardwoods will remain so, but species composition will vary greatly depending on geographic location, site type, and management practices. Sugar maple will become more dominant on many mesic sites.

- ▲ The acreage of red pine plantations is likely to dominate local areas, particularly on forest industry lands. Jack pine acreage is decreasing. Most is going to red pine plantations.

- ▲ Because of great disparity between economic and biological maturity of most tree species, the increase of old-growth forests, in a biological sense, is unlikely. Increased utilization prevents development of old-growth characteristics in managed mature forests.

- ▲ Clearcuts and plantations will continue to fragment large, uniform blocks of mature mesic hardwoods. Temporary edges caused by forest cutting will continue to dominate the northern landscape.

- ▲ Small, permanent grassy openings will continue to decline to less than 1% of public and forest industry lands. Wildlife dependent on grassy, open areas will decline (McCaffrey and Creed 1969).

- ▲ Balsam fir and tag alder will continue to dominate the former white cedar forests. White cedar and Canada yew reproduction will be restricted to scattered, local areas.

The major forest cover types of the northern forest are managed at an economic rotation age. Old-growth forests and old-growth characteristics in managed forests do not develop. Only selected economic tree species, a few forest game species, and selected endangered or threatened species receive funding and management attention. The result is a mosaic of many small stands of widely different age classes.

- ▲ The scattered relict stands containing hemlock and yellow birch will continue to decline. Reproduction of these species will be restricted to scattered, local areas (Eckstein 1980).
- ▲ Fire will not play a significant role as an ecological agent in the northern forest.
- ▲ Road networks will continue to be improved and expanded. Currently, 46% of the northern commercial forest is within 1/4 mile of an improved road (Smith 1986).
- ▲ The demand for forest products such as pulpwood, sawlogs, white-tailed deer, ruffed grouse, characteristics such as wild country and solitude will continue to increase.

Actions Causing Concern

The major forest cover types of the northern forest are managed at an economic rotation age. This perpetuates a simpler local and regional age structure of forest communities. Old-growth forests and old-growth characteristics in managed forests do not develop. More intensively managed forests lack the snag and den-tree component as well as the horizontal and vertical structure typical of old-growth stands.

Only selected economic tree species, a few forest game species, and selected endangered or threatened species receive funding and management attention. The result is a mosaic of many small stands of widely different age classes. Temporary edges are abundant. Large blocks of unbroken mature mesic forest remain rare. Fire as a natural process is rare and is not currently used as a management tool in most areas.

There is pressure by hunters to raise white-tailed deer population goals. Some plants such as Canada yew, hemlock saplings, and some orchids are quite sensitive to deer and snowshoe hare herbivory and decline with locally high deer and hare populations.

Road networks are improving and expanding so that they dominate the landscape in most areas. Housing and recreation interests are developing in more and more wild land, particularly in Oneida, Sawyer, Vilas, and Washburn counties. Large blocks of undeveloped country are declining throughout the northern forest.

State and county agencies currently use no regional landscape overview and do not utilize a unified regional classification system. Forests are managed on a stand-by-stand basis with a bottom-up forest reconnaissance system. There is little consideration of forest patterns and processes using a top-down regional landscape approach. In many cases economic rather than ecological decisions determine management direction. National, state, county, and local public land units plan management strategies independently.

Some orchids are quite sensitive to deer and snowshoe hare herbivory and decline with locally high deer and hare populations. Showy ladyslipper. *Photo by Staber Reese.*

Socio-Economic Issues

In the recent past the forest was used primarily as a source of wood products. With the exception of a few periods when there was some concern over the diminishing forest resource, the public was generally unconcerned about the treatment of forests. Biological resources not conspicuously related to timber were largely unrecognized.

These attitudes have changed greatly in recent years. Conflicts between traditional uses of forests, recreational demands, and concerns for natural ecosystem preservation are intensifying. While all factions agree that each has valid concerns, agreements on the future use of forest resources are becoming more and more difficult to reach.

Although the public is better educated about environmental issues than it has been in the past, numerous misconceptions about the nature of forest ecosystems persist. Many see any disturbance, particularly fire and clearcutting, as unnatural and always detrimental. The process of change through natural succession is seldom appreciated. There are numerous attempts at "preserving" community types that are successional. The hands-off approach is often considered as the only solution to many problems, even though indirect effects of humans are most often present (e.g., introduced insects and diseases, exotic plant species, air pollution, acid deposition, exclusion of fire, etc.).

Development of ecologically sound, cost-effective techniques encouraging natural processes on the forest landscape will require partnerships with the forest landowners, including the forest industry. Public pressure to pay more attention to maintaining complete and functional forest ecosystems will surely continue.

Although the public is better educated about environmental issues than it has been in the past, numerous misconceptions about the nature of forest ecosystems persist.

Potential for Community Restoration

There is great potential for maintaining and enhancing biodiversity in the northern forest. The basic elements of the conservation of biodiversity in forests include tree species composition, stand age, stand structure, and stand area. The key is to use a landscape management approach that accounts for all the characteristic successional stages with forest stands ranging from small to very large (Hunter 1990, Crow 1991, Probst and Crow 1991, Freemark et al. 1993, Haila et al. 1994) (Fig. 14). Characteristic successional stage refers to all age classes from seedling through old growth. These successional stages should occur in all stand sizes from small 40-acre stands to large 2,000-acre stands.

Sugar maple stand with a history of logging. Heavy sapling layer shades out ground layer except for maple seedlings. *Photo by Michael J. Mossman.*

Public lands occur across the entire northern forest on all major landforms and soil types. The distribution and abundance of public lands present an opportunity to meet multiple objectives on a landscape scale. Different landscape objectives can be met on different public land ownerships, depending on the degree of cooperation among agencies. For example, large unmanaged tracts could (and do) occur on National Forests, smaller unmanaged tracts on state forests, and small natural-area-sized tracts on county forests. A regional landscape approach can incorporate management of some forest ecosystems to feature certain species such as white-tailed deer and ruffed grouse while managing other forest ecosystems for plants and animals that require large blocks of mature forest or old-growth forest. The challenge is determining what agency does what, how much, and where.

We suggest that the record of presettlement vegetation be used as an aid but not an absolute model for determining the "desired state" of forest vegetation in a particular area. There are numerous reasons for this. Most importantly, the presettlement vegetation, as reconstructed from survey records, represents communities based only on dominant tree species present in a particular time period. Subsequent studies, based on hundreds of stands, clearly show that forest communities sharing common dominants often exhibit significantly different floristic compositions when entire floras are compared (Kotar 1987). Similar differences also exist in productivity, rates of succession, associated animal species, and perhaps in other ecological conditions not yet studied.

The forest habitat type classification system (Kotar et al. 1988) is another tool that can be used for assessing the desired state of vegetation on different sites and especially for evaluating the potential for restoring a chosen condition.

Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium..

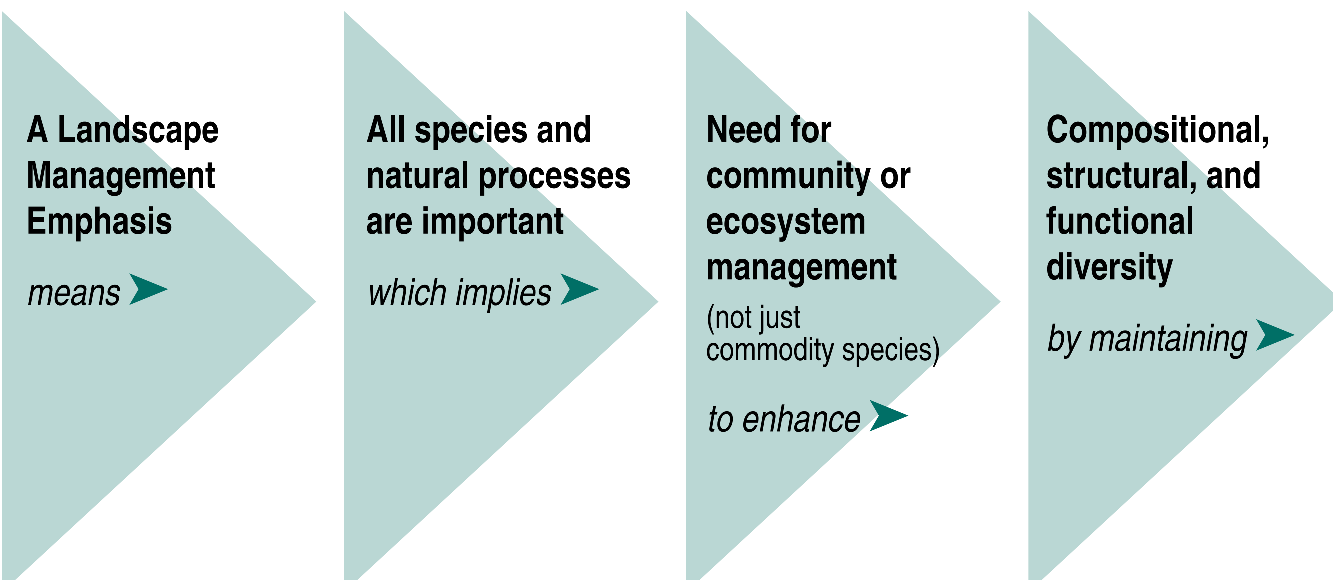
1. Facilitate inter-agency cooperation by creating a Northern Forest Working Group. This Working Group would coordinate information exchange among the various agencies and groups managing the northern forest community. The Working Group could act as a clearinghouse for information and could facilitate coordinated landscape planning. For example, meetings have begun between USDA Forest Service, the Department, and the County Forest Association collaborating on research and information-sharing.

2. Encourage the integration of the planning and management functions within each of the land management agencies in Wisconsin. All featured-species forest management guidelines (including forest game, forest vegetation, and endangered, threatened, and nongame species) and all new ecosystem management guidelines should be integrated into one handbook.

3. Encourage inclusion of ecosystem management elements in the Managed Forest Act. Develop guidelines for private landowners to enhance biodiversity. Local diversity could be maintained and improved by developing

Figure 14

Framework for application of a landscape approach within ecosystem management.



guidelines for snags, den trees, old growth, sensitive habitats, protection of hemlock and white cedar, reserve trees, and extended rotations.

4. Plan and manage public lands using a landscape-scale ecosystem approach. Use a top-down hierarchical approach to plan management across large landscape ecosystems (Noss 1983, 1992; Mladenhoff and Pastor 1993; Bailey et al. 1994) (Fig. 15).

   - Implement the Forest Accord by using the National Hierarchy of Ecological Units (Bailey et al. 1994) combined with the Habitat Classification System (Kotar et al. 1988) to the greatest extent possible. Ecologically based maps would provide information on spatial patterns and interactions of landform, soils, climate, cover types, and potential natural vegetation (Albert 1992, 1993; Bailey et al. 1994). Landscape-scale ecosystem mapping must be coordinated between agencies and landowners across the northern forest so terminology and techniques are consistent.

   - Determine how the various public lands fit into regional and large landscape ecosystems. Then, based on the type of public land, identify how the various public properties can be managed to meet local, regional, and national objectives. Examples include county forest lands, Department managed lands, lands managed by the Board of Commissioners of Public Lands (School Trust Lands) and National Forest Lands. Protect the unique biological, scientific, aesthetic, and educational opportunities on these lands.

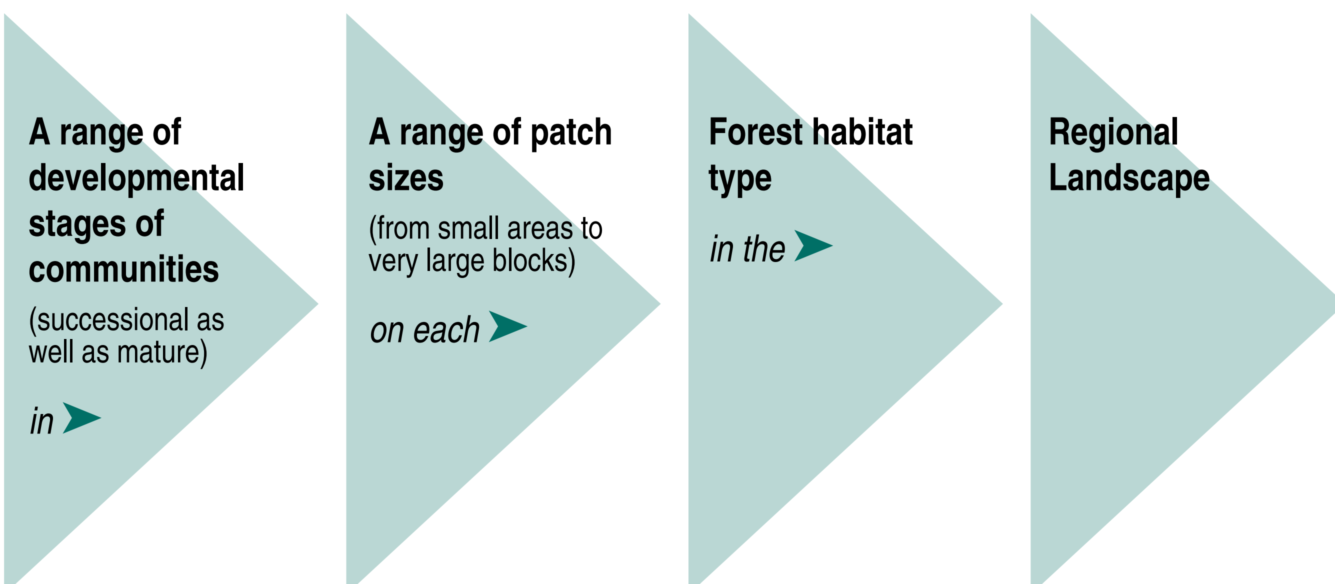
   - Continue implementation of a system of designated natural areas that represent the full spectrum of biological communities across the northern forest.

5. Develop an old-growth policy for state land and encourage the application for old growth on county land.

   - Develop operational definitions of old growth for Department managed lands.

   - Defer cutting of existing old growth on state land until an old-growth policy is established.

   - Old-growth areas in the northern forest must be large enough to meet compositional, structural, and functional objectives (Vora 1994).



Current literature suggests that there are three factors that contribute to the effective size of an old-growth patch: (1) actual size (with a minimum area constraint), (2) distance from similar old-growth patches, and (3) degree of habitat contrast of intervening forest (Harris 1984, Vankat et al. 1991, Vora 1994).

- ▲ A way to enhance each old-growth patch's effective area is to surround each with a mature forest zone managed with single-tree or group selection methods (Mladenhoff et al. 1994). The approach of imbedding old-growth in mature forest zones serves to enhance composition, structure, and function. Efforts should be made to link old-growth patches through use of riparian zones, aesthetic zones, or natural areas.

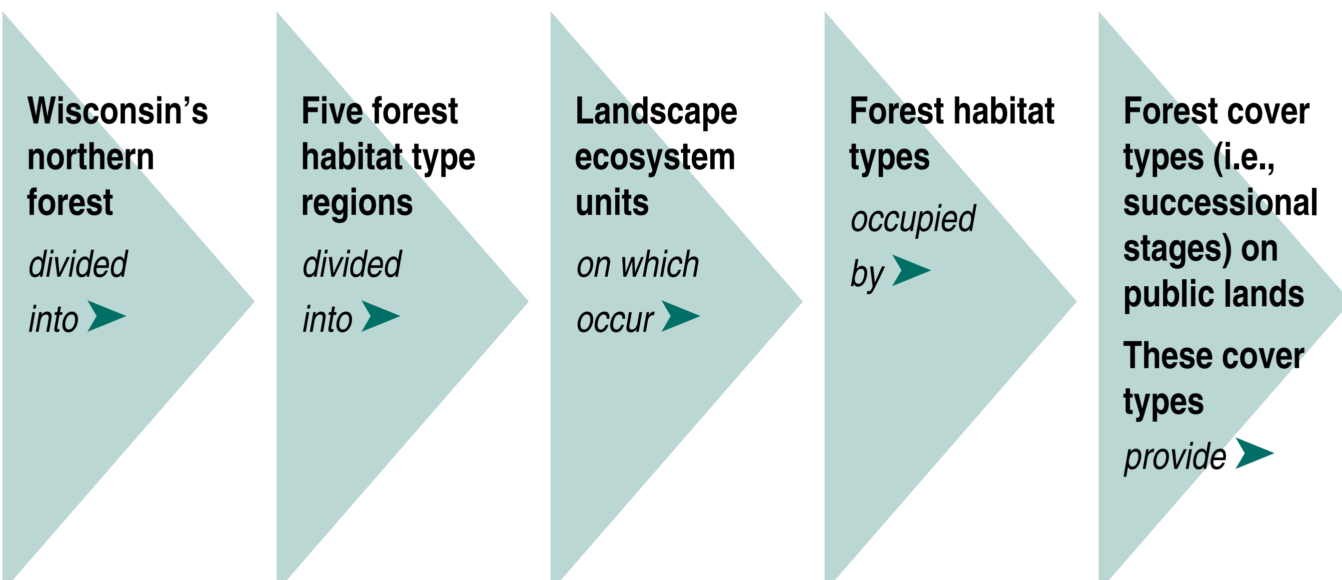
6. Increase relative stand size to reduce edge and increase forest interior conditions. Patch (stand) size is smaller in today's forests compared to presettlement forests (Mladenhoff et al. 1993). In the context of the extensive forest, stands with sizes of 200 to 2,000 acres tend to develop interior conditions favored by a variety of plants and animals. This recommendation applies to all upland forest types. Landscape planning can help determine the best opportunities to reduce edge and increase forest interior conditions.

7. Continue to improve structure and composition in managed forests.

   - ▲ Apply big-tree silviculture methods, a system originally designed to achieve aesthetic objectives, on state and county forests. Big-tree silviculture is a powerful tool to enhance diversity within and between stands.
   - ▲ Based on a landscape analysis, determine the need to extend the economic rotation for some even-aged stands.
   - ▲ Develop guidelines for structural and compositional characteristics in managed stands. These include large-diameter trees, supercanopy trees, large standing snags, mast trees, large den trees, and large downed trees.
   - ▲ Continue developing guidelines for sensitive habitats such as riparian zones, rare-plant zones, and sensitive-soil zones.

Figure 15

Decision framework for managing on a landscape scale.



- Develop prescriptions to maintain tree species diversity. Maintain hardwoods such as oak and red maple in pine stands and intolerant hardwoods such as basswood, yellow birch, and white ash in sugar maple stands.

- Protect and enhance relict stands of hemlock and white cedar. Enhancement of these stands for species regeneration may require active or non-active management scenarios.

8. Analyze road densities and develop policies for roads on Department managed lands; encourage consideration of this issue on state and county lands. Use landscape scale units to analyze logging road distribution, quality, and abundance. Reduce road densities to protect sensitive plant and animal species and sensitive areas.

Aerial view of small Iron County farms fragmenting the northern forest. *Photo by Michael J. Mossman.*

Young Forest

with ➤

Stands of many sizes composed mostly of intolerant types including forest openings

to benefit ➤

Deer and other forest game and associated species

to Mature Forest

with ➤

Stands of many sizes composed mostly of tolerant types including old growth

to benefit ➤

Interior and old growth specialists and associated species

Case Study

Marathon County Forest: Using GIS to Manage Forest Interior Habitat

Contributed by Mark Heyde, Ron Eckstein, and Becky Isenring.

Marathon County owns and manages a 26,747-acre public forest made up of many tracts, mainly concentrated in three areas of the county. Each tract, large and small, is imbedded in a matrix of agricultural and private forest lands. Although this county is on the southern edge of the range of northern forest, it provides a good example of how ecosystem management principles help us address issues of biodiversity across the northern forest.

Populations of a large group of songbirds, neotropical migrants, are in decline worldwide. Although it is not clear which of several factors are most responsible for their decline, the Marathon County Forest wanted to do what they could to contribute to the long-term viability of neotropical migrant bird numbers. Some evidence suggests that nests in small forest blocks are susceptible to high rates of parasitism, predation, and competition from species that tolerate edge habitat. In general, small forested tracts situated in agricultural landscapes provide little habitat suitable for species that are dependant upon forest interior conditions.

Marathon County decided to try to address the needs of the neotropical migrants using a Geographical Information System (GIS). They are using the GIS to analyze the county forest, generating an overview of forest stand types, sizes, and ages within the context of the Marathon County landscape. The GIS is queried for the location of possible and potential interior-forest bird habitat, using guidelines from research in the Hoosier National Forest in Indiana that were adapted to reflect conditions on the southern front of Wisconsin's northern forest. For example, edge was defined in terms of forest stand structure, size of forest openings, location of roads, and the location of nearby agricultural fields. These parameters, applied to GIS map layers, are being used to design a forest management system that reduces edge effects and enhances the area of interior forest habitat.

Marathon County is using a hierarchical approach to look at multiple scales of space and time in planning and designing management activities. The manager considers where the Marathon County Forest is located in the state while considering the position of individual county forest parcels and their composition. With this broad array of information at hand, the manager can lay out a variety of possible future conditions for the Marathon County Forest. In the planning, a wide range of options can be considered, including those that benefit interior forest songbirds.

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CHAPTER 5

Southern Forest Communities

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Description

Describing forests in southern Wisconsin (south of the tension zone) is more difficult than describing forests in northern Wisconsin. One complication is that this region includes both glaciated and unglaciated landforms, which together include soils that range in age from 15,000 to perhaps 750,000 years. Another complicating factor is the important role of fire during a period lasting perhaps 5,000 years, up to the time of Euro-American settlement, with the peak of this xerothermic period occurring 3,500 years ago.

> The southern forest is contrasted with the northern forest by the ecological importance of several species of oak and by the presence of several tree species normally not found north of the tension zone

In broadest terms, the *southern forest* is contrasted with the northern forest by the ecological importance of several species of oak (red, white, black, bur, northern pin, and swamp white) and by the presence of several tree species normally not found north of the tension zone (shagbark hickory, hackberry, boxelder, and black walnut). Bitternut hickory and butternut, which occur only occasionally in northern forests, are common although not abundant in the south. Equally important is the general absence of conifers (white spruce, balsam fir, hemlock). Pines, especially jack pine, occur in scattered areas of sandy soils.

Curtis (1959) classified southern Wisconsin forests into five community types, based on existing overstory composition: wet, wet-mesic, mesic, dry-mesic, and dry. Only the upland types (mesic, dry-mesic, and dry) will be considered here. Mesic forests are characterized by the dominance of so-called mesic hardwoods, mainly sugar maple, basswood, and American beech in the extreme eastern part of the state. Ironwood, American elm, and white ash are common associates. Dry-mesic forests are dominated by red and white oak, and dry forests are dominated by black, white, and bur oak. Hickories are common associates in both dry-mesic and dry types, while mesic hardwoods are frequently present as less important associates in dry-mesic types.

A system of finer divisions into "habitat types" based on ground layer and shrub species as well as canopy species has been developed by Kotar et al. (1988). The system has been valuable in developing forest management plans for specific sites. This system takes into account the fact that all tree species have wide ecological amplitudes and often occur as temporary dominants on sites where they do not maintain themselves in competition with other species. For example, stands dominated by red and white oak may occur as a result of fire disturbance on both mesic and dry-mesic sites. However, the associated flora on the two sites will differ significantly. Thus the two communities are less alike than their canopy composition would suggest. Also, with the exclusion of fire, the oak community on the mesic site will rapidly succeed to mesic dominants, whereas the community on the dry-mesic site will either remain as an oak-dominated community or will succeed to mesic species over a much longer period.

Because the function of an ecosystem is dependent on both its biotic and abiotic makeup, it is important to distinguish between communities with different overall species composition. In other words, two communities dominated by the same trees species may be functionally very different. If biological diversity is to be a factor in the development of management strategies, our understanding of relationships between physical site and community composition must be enhanced.

Because the function of an ecosystem is dependent on both its biotic and abiotic makeup, it is important to distinguish between communities with different overall species composition. In other words, two communities dominated by the same trees species may be functionally very different.

Status

Past

Post-Glacial Environment

Only the eastern half of the state south of the tension zone was glaciated during the most recent stage of the Pleistocene. The relationship between various glacial landforms and basic soil types, as outlined in the section on the northern forest, also applies here. Most of the southwestern portion of the state, known as the Driftless Region, has escaped glaciation at least over the last 750,000 years. However, contrary to common belief, the region was not entirely surrounded by ice at any time; thus there was always an open route for migration of flora and fauna. In fact, the significance of the Driftless Region has more to do with its function as a source of flora and fauna for post-glacial reinvasion of glacial regions than it does with uniqueness of its soil parent material. Most of Wisconsin's landscape is covered by varying depths of wind-blown silt (loess), originating in the Mississippi floodplains. Thus the composition of the soil parent material and age of soils in glaciated and driftless regions differ less than would be expected.

Current floristic distribution in the state suggests that enough time has elapsed since the retreat of the continental ice sheet for most plants and animals to reach suitable habitats. Current differences in species composition of communities in similar environments are presumed to be due to differences in disturbance histories and chance events.

Current differences in the species composition of communities in similar environments are presumed to be due to differences in disturbance histories and chance events.

Composition of Presettlement Forests

As is true for the northern forest, the exact nature of the floristic and structural composition and the geographic variation of the southern forest before Euro-American settlement has never been described and will probably never be known with certainty. However, descriptions and occurrences of prominent forest types, at least in terms of tree species composition, were recorded by numerous early observers (e.g., Knapp 1871, Chamberlin 1877, Warden 1881). These observers recognized southern forests as distinct from northern types even though many tree species occurred in both regions. The predominance of oaks and general absence of conifers were key distinguishing features noted by all observers. Another feature of southern forests often singled out by early travelers was the relative openness or park-like appearance due to the lack of small trees and shrubs. For example, one could easily ride on horseback through the woods, a condition much less common in northern forests.

The best source of information on the composition of vegetation in Wisconsin during the earliest period of Euro-American settlement comes from the records of the rectangular survey of public lands (General Land Office Surveys). The nature of these records and methods used to interpret them for purposes of constructing maps of presettlement vegetation have already been summarized in the section on the northern forest community. A simplified map of presettlement vegetation constructed from survey records by Finley (1976) is shown in Figure 10.

Seven of the 11 forest types recognized by Finley occur in northern Wisconsin and have already been described. The four southern types are as follows:

- Sugar maple-basswood with red oak, white oak, or black oak as major associates. This type of forest occurred in three major blocks, one centered in Richland and Vernon counties, another in Washington and Dodge counties, and a third in Pierce County. Numerous small segments occurred in other counties, particularly Grant, Green, Lafayette, and Sauk counties.

- American beech—sugar maple—basswood with red, white, or black oak as major associates. This type was similar to Type 1 above, except that beech was often dominant or shared dominance with sugar maple. This type occurred in a narrow north-south belt along Lake Michigan. It also coincided with the geographic range of beech in southern Wisconsin.

- White-oak—black-oak—bur-oak. This loosely defined type occurred in a seemingly random pattern throughout the region south of the tension zone.

- Oak openings: bur oak—white oak—black oak. This savanna community type often occurred as a transition between oak forest and prairie. This type could not always be distinguished from Type 3 on the basis of surveyors' records. Often it was not possible to determine whether the trees occurred in a close enough spacing to represent a true forest or whether they occurred as openings or savanna. This forest type is discussed in detail in the "Oak Savanna communities" section of this report.

Factors Controlling the Dynamics of Presettlement Forests

Explaining the composition, distribution, and dynamics of southern Wisconsin's forests has been a challenge to plant ecologists and foresters for generations. Although we do not yet have all the answers, a consensus is emerging on many issues. Over the last century, the region south of the tension zone has been regarded by some as part of the more extensive eastern oak-hickory forest or even oak savanna (Kuchler 1964) and by others as maple-basswood forest (Daubenmire 1936, Braun 1950). The presence in the region of both mesic maple-basswood forests (greatly resembling the clearly mesic northern hardwoods forests) as well as drier oak forests and even savannas and prairies caused much misunderstanding and confusion. However, ecological evidence accumulated to date clearly suggests that without regular, moderate to severe fire disturbance, southern Wisconsin's climate **can** support mesic forests on most loamy soils. Only on sands or shallow loams on southern and western exposures can oak forests be expected to persist. Without fire, perpetuation of prairies and savannas, including oak openings, is virtually impossible.

> There is ample evidence that the vegetation mosaic at the time of Euro-American settlement was largely a result of fire regimes that existed for 5,000-6,000 years prior to that time.

There is ample evidence that the vegetation mosaic at the time of Euro-American settlement was largely a result of fire regimes that existed for 5,000-6,000 years prior to that time. Because of differential sensitivity of tree species to fire damage, the communities in existence prior to Euro-American settlement were clearly related to the frequency and intensity of fires. All mesic hardwoods and particularly sugar maple are easily killed by fire at all stages of growth. Oaks, on the other hand, have many adaptations to fire environment. Saplings and seedlings of all oak species native to Wisconsin resprout readily when tops are killed. Bur oak has the greatest capacity for resprouting, followed by black, white, and red oak. Mature trees also possess varying degrees of resistance to fire damage, in the same species order.

Thus, mesic forests could persist in southern Wisconsin only on those landscapes relatively free of fire disturbance. Surveyors' records clearly showed that such forests occurred where rivers or lakes formed firebreaks against fires driven by the prevailing southwesterly winds. Landscapes subject to moderate fire frequency supported oak forests, while those more frequently burned supported oak openings or other savanna types. Each of these community types, once developed, contributed toward its own perpetuation. Thus, open grasslands burned most readily while mesic forests were far less likely to burn due to their more humid interior condition, lower wind speed, and lack of flammable vegetation.

> Euro-American settlers converted extensive acreages of southern forest to agriculture.

Climax and Old Growth

In the section on northern forests, we discussed how site conditions (e.g., soils, topography) limit the development of climatic climax and how the floristic composition of a community can be used to characterize and classify communities and sites. In southern Wisconsin this process is complicated by fire history. We cannot be sure that the floristic differences between two physiographic types or soil types are due to site constraints or to fire history. We are currently conducting extensive floristic sampling of forest stands stratified by site factors and presettlement vegetation types. This information should help us to better understand the dynamics of southern forest types.

The concept of "old growth," as understood in the context of northern forests, is applicable in the south only to the mesic community types, which are the only types capable of maintaining themselves without disturbance. However, old-growth dry-mesic and dry forests, while very rare today, were maintained by naturally occurring disturbances such as fire. These natural ecological dynamics are essential to the maintenance of these and other climax and old-growth communities. There are probably no true old-growth oak forests left in southern Wisconsin, with the possible rare exception of those oak forests growing on the mid-slope area of north and east slopes of very steep southwestern Wisconsin ridges. Some of these forested ridges of the Driftless Region exceed 450 feet in height, and only those portions of the side slopes that could be reached with cable were logged. This commonly left old-growth strips 200-300 feet wide at mid-slope, extending the length of the ridge. Today, those strips are imbedded in second-growth forest growing above and below.

The Logging and Euro-American Settlement Era

There was a significant difference in the impact of Euro-American settlement on northern and southern Wisconsin forests. While in the north the impact was mainly on forest composition; in the south, Euro-American settlement meant elimination and conversion to agriculture of extensive forest acreage. Forests not cleared for farming were almost universally high-graded for lumber, fuelwood, railroad ties, and other products and were subsequently or simultaneously grazed by cattle or sheep. Because wild fires were also suppressed with Euro-American settlement, former oak savannas not used for farming rapidly transformed into oak forests of generally low economic value.

Present

Vegetation

Because oaks are intolerant of shade, the heavy cutting that went on for several decades after Euro-American settlement stimulated oak reproduction, even in mesic forests originally dominated by maple and basswood. Subsequent selective cutting of these forests again created the environment more favorable to tolerant hardwoods.

Perhaps the most conspicuous characteristic of the present southern forest as a whole is its fragmentation. Percentage of forested area for various southern counties ranges from almost zero in some eastern counties to 30% or 35% in the western "coulee" region. The remaining forests exist mostly in small blocks or patches. Some notable larger blocks are found in the Baraboo range, the northern unit of the Kettle-Moraine State Forest and the Kickapoo River valley region. The general condition of southern Wisconsin forests is perhaps of greater concern to foresters than it is to ecologists. Red and white oak are of considerable economic value, but their supply is decreasing. The initial impact of Euro-American settlement actually resulted in an increase of oaks in present stands. Because oaks are intolerant of shade, the heavy cutting that went on for several decades after Euro-American settlement stimulated oak reproduction even in mesic forests originally dominated by maple and basswood. Subsequent selective cutting of these forests again created the environment more favorable to tolerant hardwoods. Thousands of acres of previous oak savannas not utilized for farming rapidly grew into dense oak forests through sprouting of the fire suppressed root stalks called "grubs." However, these forests are not regenerating. If mesic hardwood seed source is lacking, many of these forests will gradually break down and revert at least temporarily to shrub communities.

Perhaps the most conspicuous characteristic of the present southern forest as a whole is its fragmentation.

Animals

The forests of southern Wisconsin prior to Euro-American settlement supported a rich fauna that included large herbivores and carnivores such as bison, elk, white-tailed deer, cougar, bobcat, and black bear, and a great variety of smaller mammals as well as wet-forest furbearers—mink, otter, beaver, and muskrat (Jackson 1961)—and a rich avifauna. Remaining habitat patches, most of them less than 125 acres, appear to still support most of the species found at the time of Euro-American settlement. Many of the generalists and adaptive species have increased their populations (e.g., deer, raccoon, skunk, red fox, robin, blue jay, and cowbird). The wild turkey has been successfully reintroduced over the past 15-20 years.

Today, except for the deer and coyote, all of the large herbivores and carnivores are absent from southern Wisconsin, and a number of them are gone from the state. These species losses and other concerns in faunal composition and survival in the southern Wisconsin forests are a result of forest fragmentation and ecological simplification brought on by the rapid spread of agriculture and urbanization along with unregulated subsistence and commercial hunting.

Birds provide the best insight into the status of southern forest animals, for birds have been far more intensively researched and are subject to more regular surveys than any other animal group. Though it remains largely intact today, this faunal group is faced with mounting problems. The passenger pigeon, a colonial forest bird that inhabited the southern Wisconsin forests, is extinct. While only two other birds, the carolina parakeet (extinct) and the swallow-tailed kite (extirpated), have been lost from the southern forest landscape, many species have been negatively impacted by habitat loss, reduced size of habitat area, and changes in the composition and structure of forests and woodlots. These changes have affected bird distribution and abundance to the point where many species are listed as endangered, threatened, or of special concern, and others show significant population declines.

For example, Bond (1957) noted that interior forest species preferred larger and more mesic forests, while generalists and disturbance-preferring species showed affinity for smaller, pioneering forests. In a study of southern flood-plain forest, Mossman (1988) found that at least 20 species appeared to require stands at least 40 acres in size, and some required much larger tracts. There are at least 12 songbirds that depend on forests in excess of 40 acres in size, with three requiring a minimum of 161 acres and five more requiring either 200-acre or 240-acre woodlots to have at least a 50% chance of supporting a breeding population (Temple 1988). The average size of a southern Wisconsin woodlot is currently 47 acres. Consequently, many of these area-sensitive, interior-dependent songbird species are decreasing in frequency and undergoing population declines (Ambuel and Temple 1982, Wis. Dep. Nat. Resour. 1991).

Ecological simplification has also impacted southern forest avifauna. Reduction in area is often accompanied by grazing, logging, and cutting and gathering of firewood, activities which have altered both forest composition and structure. For example, over-grazing eliminates understory grasses, herbs, and shrubs, depriving insect and foliage-gleaning foragers of a source of food. Habitat for cavity-nesting and insect-foraging birds is removed through logging and wood-gathering.

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Many observers have noticed a significant increase in forest edge bird species (Bond 1957; Howe and Jones 1977; Ambuel and Temple 1982; Robbins 1991; David Sample, Wis. Dep. Nat. Resour., pers. comm.). One species that has benefited from increased edge is the brown-headed cowbird. Brittingham and Temple (1983) have shown that the cowbird, a brood parasite on forest songbird species, has reduced reproductive success for a number of forest songbirds and may be responsible for their recent declines. An additional concern is the role that edge birds play in predation of interior species. As crows, blue jays, and grackles increase in number, so too will their predation on forest nesting birds increase. Brood parasitism and predation, along with other elements of habitat loss and modification, have combined to create “population sinks,” poor-quality habitats in which populations produce deficit numbers that require subsidization from other populations (Whitcomb et al. 1981).

Mammals are much more poorly understood than are birds in relation to the southern forests. Lack of comprehensive inventories and population surveys means that most current knowledge is based on

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The extensive floodplain forest along the St. Croix River in Polk County harbors many species of interior-nesting birds, while the small patches of forest in the distance lack these bird species. *Photo by Eric Epstein.*

The average size of a southern Wisconsin woodlot is currently 47 acres. Consequently, many area-sensitive, interior-dependent songbird species are decreasing in frequency and undergoing population declines.

observations and relatively few studies of local species populations. However, mammals in general don't seem to show the same correlations with habitat area and quality decline as birds do (e.g., species decline, or in mammals, abnormal rhythms) (Frank Iwen, UW Zoological Museum, pers. comm.). In general, forest mammals are secure, with some species' populations apparently increasing, such as voles, mice, and shrews, where understory composition and structure are well protected and maintained. There also appears to be an increase in forest mammalian predators that are capitalizing on the increased small mammal populations (Frank Iwen, pers. comm.).

The white-tailed deer has, over the last 25-30 years, expanded its range southward and is present in great abundance in southern forest and woodlots. In some areas their numbers are so great that browse impacts are readily observed by the elimination of some plant species (e.g., certain orchids and Canada yew) and reduced reproduction of cedar, oak, and maple, among others. Deer negatively affect cover for ground nesting birds. Numbers of deer continue to increase, and this species' range is expanding into all suitable habitat.

A few mammalian species have not adapted well to current conditions. Loss of forest structure and spraying for insect control in agricultural areas has posed problems for the southern forests' solitary bats. Fox squirrels also appear to be declining in southern forest edge, as these areas convert to closed forest.

Little is known about the historic or current abundance of southern forest amphibians and reptiles (herptiles). Regional distributions studies for herptiles are ongoing by a group of amateur and professional herpetologists as part of the Wisconsin Herpetological Atlas Project (Casper 1986). The DNR has been conducting an annual frog and toad survey since 1981 to determine the population trends of these species (Jansen and Anderson 1981, Mossman and Hine 1984, Mossman and Huff 1990, Huff 1992). This survey was initiated because of the concern that amphibian populations were declining for some species in Wisconsin and globally (Modern Medicine 1973, Les 1979, Hine et al. 1981, Vogt 1981)

Several southern forest amphibians are susceptible to changes in habitat structure. These primarily include the species dependent on ephemeral or vernal ponds for breeding, such as the chorus frogs, eastern gray and Copes gray tree frogs, wood frogs, and blue spotted and eastern tiger salamanders (see "Actions Causing Concern" section). Snakes associated with the southern forest that are of concern include the black rat snake, timber rattlesnake, and massasauga rattlesnake. The impacts of natural succession, forestry practices, and other land-use and management activities on these species are not well understood. The timber rattler and black rat snake are communal denning snakes whose local populations are susceptible to losses of critical hibernating sites. These and other communal denning snakes are also more vulnerable to destruction or collection since they are clustered in quantities especially during spring emergence from den sites (Robert Hay, Wis. Dep. Nat. Resour., pers. comm.). Both the massasauga and timber rattlers have seen demonstrable declines in populations throughout Wisconsin and the rest of their ranges. Both have been impacted by habitat loss and bounties which have virtually eliminated them from many areas. They are still killed because of their unfounded reputation as being very dangerous. The massasauga is the most seriously endangered species of reptile in the state, now restricted to only a few lowland hardwood forests, forest edges, and adjacent upland fields (Vogt 1981).

Little is known about the historic or current abundance of southern forest amphibians and reptiles .

Little is known about the invertebrates of the southern forests of Wisconsin. Diversity in forest structure plays an important role in meeting the needs of lepidopterans as well as other insects and invertebrates. Recent surveys have focused on lepidoptera, which may in the future serve as indicators of change because of their frequent association with host plants and species-specific food sources and their relative sensitivity to habitat perturbations.

Projected

Given the rate and means by which southern forest fragments in some areas, particularly southeastern Wisconsin, are being harvested and developed as rural homesites, the following trends can be expected:

- ▲ Fragmentation and reduction in size of woodlots will continue.
- ▲ Highest quality woodlands will continue to be lost.
- ▲ At the current rate of harvest, oak may cease to be a commercially viable product in the future.
- ▲ Emphasis on hardwood saw logs will in the near future shift from oak to other southern forest hardwoods such as sugar maple, black cherry, hackberry, walnut, and white ash, further reducing both long-term veneer and saw-log supply and overall species composition and stand structure.
- ▲ Forest composition will vary greatly, with both commercially and ecologically less desirable species (such as black locust, box elder, and persistent dense shrubs) replacing oak and maple forest communities in some areas.
- ▲ Poor management practices will reduce productivity, decrease long-term economic value, and diminish sustainability of the southern forest community complex.
- ▲ Fire, perhaps the most important ecological tool in establishing and maintaining oak forests, will not be employed sufficiently as a prescribed management practice.

Little is known about the invertebrates of the southern forests of Wisconsin.

Actions Causing Concern

Ecological consequences of altered vegetation dynamics, as described above, are difficult to assess. There is no question that natural community diversity of the southern forest landscape has been reduced since the suppression of presettlement fire regimes, and lack of fire in the oak woodlands and forests is a concern. In addition, native vegetation is extremely vulnerable to replacement by exotics. However, there is no clear evidence that any forest plant species have been lost. The southern forest fauna, both vertebrate and invertebrate, has apparently been more severely impacted. It appears that forest fragmentation is of primary concern in terms of faunal diversity. Additionally, structural and compositional changes from intensive land-use practices, exotic and edge species encroachment, and grazing have adversely impacted southern forest fauna. The southern forest avifauna is particularly vulnerable to fragmentation and simplification.

Forest amphibians also are a primary concern because of their vulnerability to habitat changes and pesticide use in adjoining agricultural lands. Intensive forest management and woodlot scavenging can significantly open or disturb large areas of forest, which leads to siltation and premature drying of vernal ponds, reducing or prohibiting amphibian metamorphosis (Robert Hay, Wis. Dep. Nat. Resour., pers. comm.). Also of concern in these disturbed areas is the loss of structural habitat composed of large, dead woody debris, heavy loam, and thick surface litter, which are habitat characteristics essential for amphibians (Gary Casper, UW-Milwaukee, pers.

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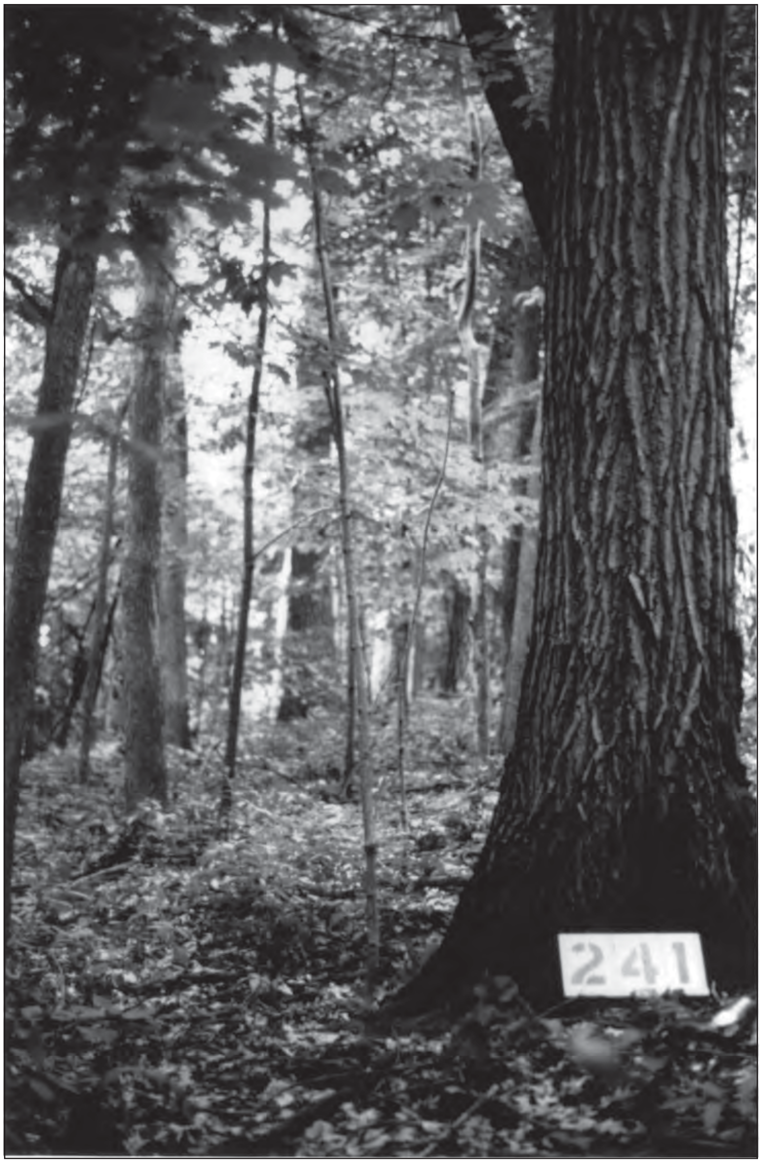

This stand of southern hardwoods is converting from oak to more tolerant species such as ironwood and red maple. *Photo by John Kotar.*

In order to maintain and restore a diversity of forest communities, extensive education of forest owners and the public will be required.

comm.). Roads near breeding areas are also a threat along with the "clean-yard" practices of homeowners building in woodlots.

Gypsy moth control efforts pose a serious threat to native lepidopterans. Aerial application of the biological control agent *Bacillus thuringensis* (B.t.) can kill native species larva. Because susceptibility to B.t. is dependent on the time of emergence, and time of emergence is variable over several weeks, native lepidopterans with synchronous emergence patterns are equally vulnerable to mortality. Agricultural pesticide use is also of concern for the invertebrate community.

Of increasing concern for the southern forest is the artificially maintained high deer density. There is now evidence that in many areas forest regeneration may be frequently reduced by deer browsing.

Socio-Economic Issues

As in all forested regions, conflicts between traditional uses of forests, recreational demands, and concerns for preserving natural communities is intensifying. Numerous misconceptions about the nature of forest ecosystems exist among forest owners as well as the general public. The process of change through natural succession is seldom appreciated. Forest owners too often agree to sell only the highest quality trees, usually oaks, and thus slowly convert their woodlots to tolerant hardwoods. On the other hand, the general public often sees any disturbance, particularly clearcutting and fire, as unnatural and always detrimental. In order to maintain a desired diversity of forest communities, extensive education of forest owners and the public will be required. Because most of the forest land in southern Wisconsin is in private ownership it may seem that public opinion does not matter. However, the public everywhere is becoming progressively more proactive, and its influence on the legislature and the courts is increasing. We should expect management decisions to be increasingly questioned.

Potential for Community Restoration

If the desired state is considered to be some representation of all presettlement forest communities, considerable difficulties will be encountered with its implementation. Restoration of oak savannas would be the most difficult, both from an ecological as well as an economic standpoint. Intensive management through the use of fire would be necessary, and without economic incentives it is not likely to be applied to private lands. Restoration and maintenance of mixed oak forests is certainly possible from the ecological point of view, but greater economic incentives and technical support will be needed to enable landowners to apply proper management techniques. Without such incentives and support, high-grading and degradation of oak forests are likely to continue. Mesic forest restoration and maintenance would be relatively easy. However, because of direct competition with farming, most forest communities will probably remain confined to terrain unsuitable for cultivation.

Today, large tracts of floodplain are limited to the Lower Wisconsin and Mississippi river valleys; most of the southeastern floodplain forests have been destroyed or reduced to small patches. Large areas of upland forest are restricted to parts of Crawford and Vernon counties, the Baraboo Hills, the northern unit of the Kettle Moraine State Forest, and parts of Manitowoc County. The potential for restoring additional large tracts of each forest type is relatively good in at least some areas of both western and eastern Wisconsin. There are also a number of swamp and bog forests still intact, though often degraded, in the south-central and southeastern counties. Many of these forests have been reduced in size by drainage, agricultural encroachment, and grazing; however, many could be restored over time by reversing the drainage processes.

The best way to enhance biodiversity across the southern forest landscape is to increase the size of individual woodlots and reduce their fragmentation. Achieving this goal will be difficult, but potential does exist in some parts of the southern forest.

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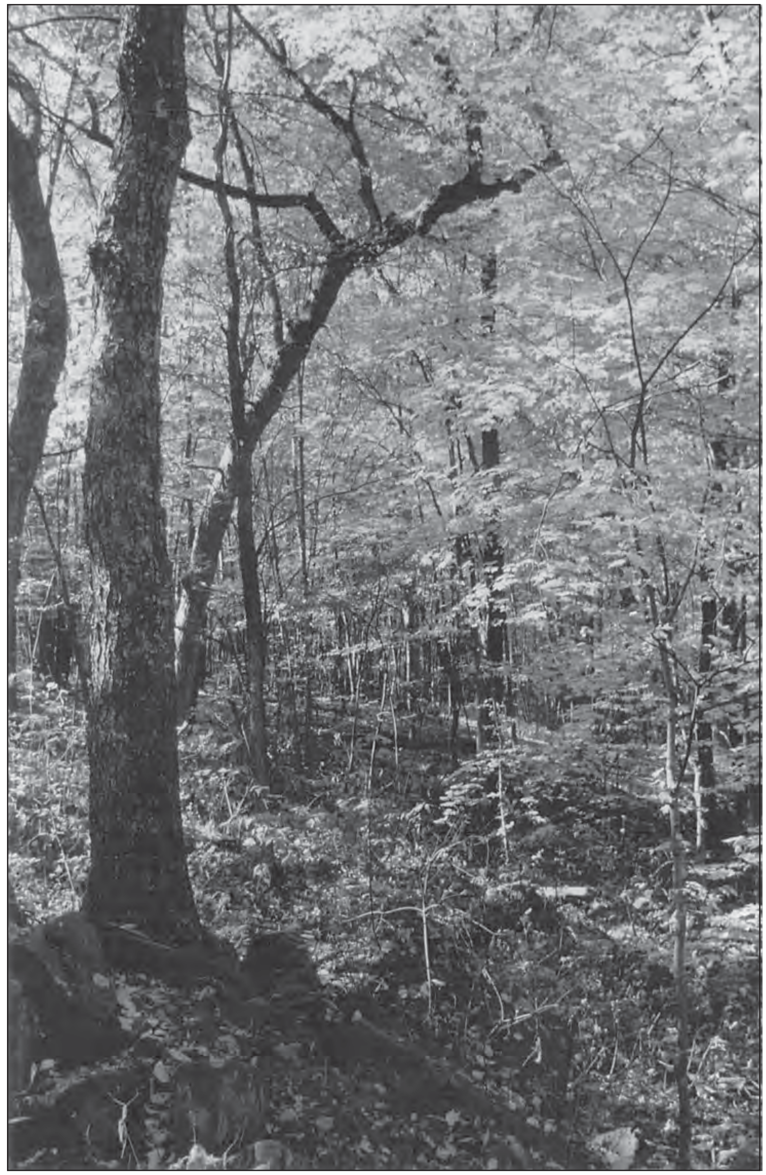
Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.



Mature southern mesic forest of sugar maple and basswood. Lost Lake State Natural Area in the eastern end of the Baraboo Hills. *DNR photo*

1. Community-specific actions:

Mesic Forest (including oak-dominated forests with presence of shade-tolerant mesic hardwoods such as sugar maple,

Mixed oak and hickory stands do not regenerate without periodic disturbance. This stand of young oak is growing back after clearcutting. *Photo by John Kotar.*

American beech, basswood, white ash, or bitternut hickory). Mesic forests are relatively stable. In the absence of periodic major disturbances, the dominance of shade-tolerant hardwoods increases. Mixed composition can be maintained with proper silvicultural techniques (e.g., shelterwood, group selection, clearcutting). For optimal biodiversity, some mesic forests should be maintained in a mixed state. Because southern mesic forests were never extensive, even before Euro-American settlement, it is recommended that they be maintained wherever they still occur.

Mixed Oak and Oak-Hickory Forest. Where no tolerant hardwoods are present, these forests are not threatened by succession; however, neither do they regenerate without periodic disturbance. It is recommended that these forests be maintained by appropriate silvicultural methods, including prescribed burning. While no single method has been shown to work in all situations, a number of techniques have been used successfully across a range of site types.

Oak Openings (Savanna). Although this community type is treated in detail separately in this report, it is included here because it is dynamically related to oak forests. Oak openings and savannas in general are among the rarest community types in Wisconsin. Over most of their former range, they have been eliminated by farming or have naturally converted to closed-canopy oak woodlots. Restoring these community types would clearly enhance local as well as regional biodiversity. Although restoration methods are still in developmental stages, it is almost certain that prescribed burning rather than mechanical manipulation of vegetation will be required. Because of predominantly private ownership, large-scale restoration of these communities will be difficult without providing additional economic incentives.

> Because the conifers are rare in southern Wisconsin's forest communities, restoring the presence of white pine and its associated communities to their previous southern range would enhance biodiversity.

Mixed Pine-Oak Communities. With the exception of the "central sands" region and a narrow belt along the shores of Lake Michigan, pines have not generally been considered as a natural component of southern forest. However, a number of scattered oak-white pine communities (e.g., Devil's Lake State Park) and several white pine relicts suggest that this type could be maintained on many landscapes. White pine and red oak have similar ecological requirements and the two species can be managed together. Because the conifer component is rare in southern Wisconsin's forest communities, restoring the presence of white pine and its associated communities to their previous southern range would enhance biodiversity.

2. Old-growth restoration and maintenance areas in southern mesic forests should first be addressed on Department lands where the largest southern mesic forest tracts remain. Areas of remnant old growth should be maintained and enhanced by allowing surrounding forest to attain old-growth condition through natural processes. On appropriate Department lands, designated old-growth areas can be enhanced by surrounding each with a mature forest management zone based on selection harvest practices (see the "Northern Forest" section Possible Actions). Private woodland owners should be encouraged to apply selection management practices, which would allow trees to reach a much older age before harvest and would build old-growth structural characteristics into their forests. Where woodlands occur in close proximity, encourage blocking through the reforestation of intervening open lands, thus enhancing mature old-growth forest characteristics of the existing patches. Encourage participation in private forest assistance programs such as the Managed Forest Law and the U.S. Forest Service Stewardship Incentive Program.

Old-growth restoration and maintenance areas in southern mesic forests should first be addressed on Department lands where the largest southern mesic forest tracts remain.

3. Whenever possible, reduce fragmentation of woodlots by enlarging current blocks and providing wooded corridors through reforestation.

4. Work toward the development of economic incentives for private landowners to enable them to participate in resource management programs that protect biodiversity. Only through such programs will it be possible to implement the specific recommendations listed in this report on a region-wide basis.

5. In order to coordinate management practices consistent with state-wide objectives, some type of regional "information center" will have to be created. For example, a land manager on a given property may be taking all the correct measures to optimize local biodiversity, but without some source of information on wider, regional needs he/she may nevertheless be acting inappropriately. In order to allow for more natural type conversions (through succession), there will be a need for planning regional rotations of cover types. Forest nurseries are producing a much greater diversity of planting stock, including pioneer species such as aspen, because management through natural succession must go hand in hand with the establishment of compensating pioneer stages.

6. Bring together the large amount of existing technical information on silviculture, forest ecology, and wildlife ecology by establishing a natural community information system. The system should have the following characteristic:

   - A basic inventory of wildlife species.

- A basic inventory of wildlife habitats and plant communities.
- A basic model of the relationships of wildlife species to these habitats (Verner et al. 1986).
- A computerized storage and retrieval system.
- Procedures for applying species habitat relationships to integrate resource planning and management.
- Guidelines for managing special habitats or stand conditions.
- A monitoring strategy.

Case Study

The Baraboo Hills: Partners Protecting and Managing in an Ecosystem Context

Contributed by Eric Epstein and Becky Isenring.

The ancient quartzites of the Baraboo Hills rise hundreds of feet above much of the surrounding landscape. Thin soils, steep slopes, low fertility, and public interest discouraged the intensive development now characterizing the vast majority of southern Wisconsin. Today the Hills are mantled with the most extensive upland deciduous forests (totalling about 55,000 acres) remaining in the southern part of the state. In a landscape dominated by agriculture, where most remnant natural vegetation occurs in small, isolated, and often highly disturbed stands, the Hills are an oasis for one of the most diverse arrays of natural communities, plants, and animals in the upper midwest.

Devil's Lake is imbedded in the Baraboo Hills and the most extensive forest in southern Wisconsin. The band of continuous forest of the south range of the Hills narrows at this point from a wider band to the west. *Photo by Michael J. Mossman.*

Naturalists, conservationists, and scientists from many disciplines have been drawn to the Baraboo Hills for well over a century. In 1911, the creation of Devil's Lake State Park marked the first effort to protect a portion of them in perpetuity. The state purchased and acquired other significant properties in the years that followed, including Parfrey's Glen (Wisconsin's first State Scientific Area), Natural Bridge State Park, Lost Lake State Natural Area, McGilvra Woods State Natural Area, and Pewit's Nest State Natural Area. Significant conservation ownerships are also held by the University of Wisconsin Foundation (Potter Preserve), the University of Wisconsin-Baraboo (Van Zelst Barrens), the Village of Rock Springs (Weidman Park), and Wisconsin Society for Ornithology (Honey Creek).

The Nature Conservancy (TNC), a private conservation organization with a large membership and history of involvement in the Baraboo Hills protection efforts dating back some thirty years, is a leading partner. Many of their active projects are focused on the most ecologically important sites in the Hills, including Baxter's Hollow, Hemlock Draw, Pine Hollow, and Misty Valley.

Until recently, most of the conservation work in the Hills had been devoted to individual projects. To take advantage of the unique opportunity for protection and management at a large scale, it was clear that a unified, expanded vision encompassing the scope and attributes of the entire ecosystem was necessary.

In 1991, TNC took a major step to support this vision by initiating a two-year biological inventory in parts of Sauk and Columbia counties, targeting an area of 144,000 acres. The area inventoried was defined principally by the underlying Baraboo quartzite. Field staff included ecologists, botanists, and zoologists. Information was collected on all types of natural communities occurring in the Baraboo Hills, and on many plant and animal species. DNR personnel from the Bureaus of Research, Endangered Resources, Parks and Recreation, and Forestry provided assistance through training, consultation, and development of sampling design. Many individuals in these programs also contributed personal records to the Baraboo Hills Inventory. The Natural Heritage Inventory provided existing computerized records for the area surveyed, a database to store and maintain records, a format to record field data, and a methodology for ranking natural communities and rare species populations.

To meet the existing and anticipated needs of forest managers in the Hills, vegetation data were collected by TNC's inventory teams under the guidance of the UW-Madison's Forestry Department. These data are being analyzed to identify habitat types, as part of a statewide Forest Habitat Classification system.

Other key partners in this endeavor included the UW-Madison herbarium staff (specimen identification), U.S. Forest Service (Forest Stewardship Fund), UW-Stevens Point (Biotic Index analysis of stream samples), numerous volunteers, and the cooperation of numerous landowners who willingly gave inventory staff access to their properties.

To enhance the value and utility of the data collected through inventory, TNC worked with the UW Land Information and Computer Graphics Facility and the UW Institute for Environmental Studies to develop a GIS for the Baraboo Hills. Information incorporated into this system includes Natural Heritage Inventory data, "presettlement" vegetation, current land ownership, natural community covers, and geology. A computer model simulating the effects of land-use changes on neotropical migrant birds has been adapted using the GIS.

Today, an exceptional opportunity exists in the Baraboo Hills to protect and manage an existing functional, diverse, forested ecosystem. The inventory has documented the ecological context for the Baraboo Hills. The new technologies have provided tools to aid in the synthesis and analysis of the information available. Now, many different public and private interests will work to support local and county leadership as plans for the future come into place. These plans will need to incorporate the inventory and other ecological, socio-economic, and political information and provide strategies to address threats, resolve conflicts, and ensure long-term success. Strong commitment to the eventual success of this unprecedented project is needed from all partners, public and private, large and small.

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CHAPTER 6

Oak Savanna Communities

by Richard Henderson
Bureau of Research
Department of Natural Resources

Description

The term *savanna* has never been well defined. It has its origin in the early Spanish colonization of the Caribbean in the 16th century, where it was applied to treeless grassy plains (Johnson and Tothill 1985). By the end of the 19th century, this Spanish term was widely used by plant geographers to describe tropical grasslands. Also by this time, woody plants had became an accepted and, in some cases, even mandatory part of the definition. By the mid-20th century ecologists were still struggling with the definition of savanna, especially in North America (Penfound 1962). Cole (1960) summed up the situation this way: "Perhaps of all types of vegetation the savanna is the most difficult to define, the least understood, and the one whose distribution and origin is the most subject to controversy." Today there is still no widely accepted, clear-cut definition of what is meant by savanna.

> The term savanna is used in the Midwest to describe an ecosystem bordered by the prairies of the west and the deciduous forest of the east—a mosaic maintained by frequent fires and possibly by large ungulates.

Fortunately for us in the Midwest, the term *savanna* has a relatively narrow definition. Here it is generally used to describe an ecosystem that was historically part of a larger complex bordered by the prairies of the west and the deciduous forests of the east. This complex was a mosaic of plant community types that represented a continuum from prairie to forest. Savannas were the communities in the middle of this continuum. The mosaic was maintained by frequent fires and possibly by large ungulates such as bison and elk. Oaks were the dominant trees, hence the term *oak savanna*.

Because savannas grade into both prairie and forest, there are no clear dividing lines between savanna and these two communities. In classifying the plant communities of Wisconsin, Curtis (1959) was forced to set limits for what he called savanna. He ultimately defined it as having no less than one tree per acre and no more than a 50% tree canopy. However, Curtis made it clear that these limits were arbitrary and chosen purely for convenience. Curtis also subdivided Wisconsin savannas into four categories based on plant composition: *oak barrens, pine barrens, oak opening, and cedar glade*. He defined *oak barrens* as savannas with black/Hill's oak on infertile, droughty sand or sandstone-derived soils. *Pine barrens* were defined as savannas with jack/red pine on similar soil types as oak barrens. *Oak openings* were defined as savannas on rich, mesic soils with mostly bur or white oak. *Cedar glades* were defined as savannas on dry limestone bluffs, with red cedar more prevalent than oaks. Another savanna community type, wet and wet-mesic soil savannas, was not listed by Curtis, because not enough intact examples could be found at the time of his study. Bur and swamp white oak were probably the dominant trees of this community historically. The following discussion mostly covers the community types Curtis called oak opening, but it applies to other savanna types as well. The sandy soil oak and pine barrens are covered in a separate chapter in this report.

Just what the understory and ground layer vegetation of oak savannas was like is largely unknown. Bray (1960) described the oak savannas as having less grass and more forbs and woody shrubs than prairie, but more grass and fewer forbs than forest. Historically, the savanna community was probably a slowly shifting mosaic of plant species associations that had varying degrees of shade and sun tolerance. Consequently, the flora of oak savanna was probably a blend of the following species:

- ▲ True "sun-loving" prairie species that can tolerate or survive only light shading.
- ▲ Prairie-associated species that do well, or perhaps slightly better, in light shade than in full sun.
- ▲ True savanna species that do best in, or are restricted to, a blend of shade and sun.
- ▲ Forest-associated species that do well with fire and moderate amounts of sunlight.
- ▲ True forest species that can persist, but do not necessarily thrive, with occasional fire and moderate sunlight.

Historically, the savanna community was probably a slowly shifting mosaic of plant species associations that had varying degrees of shade and sun tolerance.

Although oak savannas were probably relatively dynamic communities compared with prairies or forests, major vegetation changes within these savannas still took decades if not centuries to occur.

Detailed descriptions of Wisconsin oak savanna vegetation can be found in works by Bray (1958, 1960) and Curtis (1959). These studies provide the best available data on savanna vegetation; however, they should not be considered the final word on historical savanna. By the time these studies were done, the savanna as a complete ecosystem had already been gone for 100 years. The remnants available for Bray, Curtis, and others to study were limited in number and size and had probably already been altered to some degree by absence of fire and a history of domestic livestock grazing. Recent information and observations resulting from savanna restoration attempts over the past decade suggest that the original oak savanna vegetation may have been even more diverse and specialized than the Bray and Curtis studies indicate (Packard 1988*a*, 1988*b*; Bronny 1989; Clewell 1989; Pruka 1994; W. Pauly, Dane Co. Parks, unpubl. data; R. Henderson, Wis. Dep. Nat. Resour., unpubl. data).

An oak opening is a savanna on rich, mesic soils with mostly bur or white oaks. Here is a white oak with prairie-like understory in a subdivision in Dane County. This tree has typical open-grown architecture, is more than four feet in diameter, and probably got its start around the Revolutionary War. *Photo by Richard Henderson.*

The more wooded part of the historical prairie-forest complex (i.e., savanna or woodlands with 50%-100% tree canopy) is known to us only through the early accounts of explorers and settlers. This community was already so distorted by lack of fire and other disturbances by the mid-1900s that it was not even classified and studied as a separate community by Curtis and his students. What remained of this community at the time of the Curtis studies (i.e., grown-in savannas) was lumped with the dry or dry-mesic southern hardwood forest communities based on the residual oak trees, often independent of the actual soil moisture regimes of the sites. Recent research is now starting to shed some light on this plant community. Pruka (1994) studied the sorting out of groundlayer plant species along the natural sunlight gradients found in savanna and woodland.

This more heavily wooded portion of the prairie-forest complex (up to and including 100% closed canopy) might best have been described as an open oak woodland. Although much work needs to be done in describing and understanding this community, it should most likely be viewed as separate from oak forest. Based on historical accounts, it had a "park-like" structure, with the dense shrub and understory tree layers associated with oak forests of today kept sparse and low in stature by fire. The ground layer was probably dominated by forest species of low- to mid-shade tolerance (e.g., summer- and fall-blooming grasses, sedges, legumes, and composites) that are today doing best in forest gaps and edges, and savanna species of mid- to high-shade tolerance.

Oak savanna now shares equal billing with tallgrass prairie as the most threatened plant community in the Midwest and among the most threatened in the world. Intact examples of oak savanna vegetation are now so rare that less than 500 acres are listed in the Natural Heritage Inventory as having a plant assemblage similar to the original oak savanna. This is less than 0.01% of the original 5.5 million acres.

Status

Past

Oak savanna has probably been in North America for 20-25 million years (Barry and Spicer 1987), shifting about and expanding and contracting with climatic changes. For the past several thousand years it has existed in a more or less stable and continuous band covering millions of acres in what is now Minnesota, Wisconsin, Iowa, Illinois, Michigan, Indiana, Ohio, Missouri, Arkansas, Oklahoma, and Texas. Historically, what is now Wisconsin was probably a leader in total acres of oak savanna. At the time of Euro-American settlement, Wisconsin had an estimated 5.5 million acres of oak savanna (not including the 4.1 million acres of oak and pine barrens) (Curtis 1959) and an additional 1.4 million acres of oak forest, much of which may have been open oak woodland (see Fig. 10).

Present

In the early to mid-19th century, the oak savanna as an ecosystem was thoroughly fragmented and nearly totally destroyed throughout its range. Most of its acreage suffered one of the following fates: (1) clearing and plowing, (2) overgrazing, or (3) invasion by dense shrub and tree growth due to lack of fire, lack of grazing, or both. Oak savanna now shares equal billing with tallgrass prairie as the most threatened plant community in the Midwest and among the most threatened in the world. Intact examples of oak savanna vegetation are now so rare that less than 500 acres are listed in the Natural Heritage Inventory as having a plant assemblage similar to the original oak savanna. This is less than 0.01% of the original 5.5 million acres.

Many plant species that were probably savanna specialists are now uncommon and are found only in the fringes and openings of oak woods, brushy areas, and lightly grazed pastures. Some examples are yellow pimpernel, pale Indian plantain, woodland thistle, downy wild rye, elm-leaved goldenrod, New Jersey tea, sessile-leaved eupatorium, and horse gentian. Two likely savanna specialists (purple milkweed and wild hyacinth) are listed as endangered in the state and three others (kitten tails, cream gentian, and Virginia lespedeza) are listed as threatened.

Fortunately, most of the savanna species, especially the mammals, birds, reptiles, and amphibians, have readily adapted to the changed landscape, or they have managed to hang on and survive to this point in suboptimal habitat (e.g., the fringes of other less devastated communities such as oak forests). The success of the vertebrate animals has been due to the fact that major elements of the savanna structure are still well represented today in various "edge" habitats, including wooded pastures, lawns, and woodlots. The fact that the plant species may be different in those habitats has not affected savanna vertebrate species for the most part.

Many of the mammal species that were closely associated with our historical oak savannas are still doing well today (e.g., long-tailed weasel, cottontail rabbit, woodchuck, fox squirrel, red fox, and white-tailed deer). However, others have been either extirpated from the former savanna regions (e.g., timber wolf, bison, and elk) or reduced to very low numbers (e.g., bobcat and black bear). The loss of these species, however, was due more to incompatibility with high human densities than to loss or degradation of the oak savanna plant communities. Some mammals associated with the most open savannas (and the prairies) have not fared as well with the changes. For example, the least shrew and the Franklin's ground squirrel are of special concern in the state.

Most savanna bird species are still doing very well today (e.g., American robin, indigo bunting, blue jay, American goldfinch, and brown thrasher). Only one oak savanna bird, the passenger pigeon, has become extinct, and another, the turkey, was extirpated but restored; both of these were lost to unregulated hunting rather than loss of habitat. However, a number of savanna bird species have not thrived or have begun to decline in recent years (e.g., black-billed cuckoo, northern flicker, red-headed woodpecker, warbling vireo, vesper sparrow, bobwhite quail, and field sparrow). One species, the orchard oriole, is on the state's list of special concern; one, Bell's vireo, is on the state's list of threatened species; and two others, the loggerhead shrike and barn owl, are on the state's endangered species list (D. Sample and M. Mossman, Wis. Dep. Nat. Resour., pers. comm.). Although loss of habitat has not been the cause of decline in all these species, it certainly is affecting many of them. The abandonment and loss of savanna/woodlot pastures in the past few decades may be playing a role in some of these recent declines in savanna bird species.

This property in Waukesha County shows what is thought to be the typical tree structure of oak openings. Since Euro-American settlement, oak openings have almost disappeared from the landscape because of clearing, plowing, overgrazing, or suppression of fire followed by invasion by dense shrub and tree growth. As Curtis (1959) observed, "Beyond question, an oak savanna with an intact groundlayer is the rarest plant community in Wisconsin today." *Photo by Eric Epstein.*

Most of the amphibian and reptile species that were closely associated with our historical oak savannas are still doing at least moderately well today (e.g., Cope's gray treefrog, five-lined skink, eastern hognose snake, smooth green snake, western fox snake, eastern milk snake, and Dekay's snake). However, two reptiles associated with savanna habitat are suffering from habitat loss. These are the western slender glass lizard and the eastern massasauga rattlesnake; both are now on the state list of endangered species. Oak savanna sites may be important nesting sites for turtle species such as the threatened Blanding's turtle in some areas, as agriculture continues to dominate open spaces traditionally used for turtle nesting.

Unlike the vertebrate communities, our knowledge of oak savanna invertebrates is very limited. We don't know what species were characteristic or restricted to the community, let alone their current status. It is likely that many species were lost or are now very rare.

Projected

In the absence of active management, the future of oak savanna looks very bleak in Wisconsin and throughout its entire range. The increasing abandonment of lightly to moderately grazed wooded pastures and the accelerating succession of oak woodlots toward heavy-shade-producing trees and shrubs will lead to the decline and possible loss of much of what remains of the savanna flora and fauna, including eventual decline of the oaks themselves.

Actions Causing Concern

Threats to the future survival of oak savanna can be summarized in five categories.

- Loss of recovery opportunities due to
  - ✓ accelerating forest succession to dense-shade-producing species,
  - ✓ lack of recruitment and eventual die-out of long-lived plants in suboptimal habitat,
  - ✓ increasing or decreasing grazing pressure, due to changes in pasturing practices.
- General neglect and lack of knowledge about the community by the public, professional resource managers, and scientists.
- Resistance to the use of prescribed fire, especially in wooded areas, and lack of understanding by the public and professionals as to the importance of fire in maintaining the state's biodiversity.
- Invasion by aggressive exotics (i.e., honeysuckle, buckthorn, and reed canary grass).
- Increasing human population pressures, often expressed as rural home and suburban development.

> Threats to the future survival of oak savanna include the lack of knowledge about the community, the resistance to the use of prescribed fire, the lack of understanding of the importance of fire in maintaining oak savanna, and increasing human population pressures, often expressed as rural home and suburban development.

Socio-Economic Issues

Oak savanna was probably the optimum habitat for many game species (e.g., bobwhite quail, turkey, squirrels, deer, and rabbits). Thus, management for oak savanna is compatible with traditional wildlife management and hunter interests. The popularity of savanna songbirds, such as bluebirds, should also lend public support to oak savanna restoration. Light to moderate cattle grazing can be compatible with maintaining the plant structure needed by many savanna species. There is support among private conservation groups for oak savanna protection and recovery; it is a high priority for The Nature Conservancy. However, the public in general lacks knowledge about savannas.

Potential for Community Restoration

The recovery potential of oak savanna in Wisconsin is substantial (Holtz 1985; Bronny 1989; R. Henderson, Wis. Dep. Nat. Resour., unpubl. data). Degraded sites in the dry and wet ends of the spectrum can be recovered with relative ease. Mesic savannas with deep, rich soils will take more time and work, but recovery is still feasible. The pieces can still be found and put back together with a reasonable amount of effort (Packard 1988*b*). However, biological and socio-economic opportunities are gradually and steadily disappearing.

Currently there are hundreds if not thousands of acres of overgrown but retrievable oak savanna on Department-managed lands. In addition there are probably thousands of acres of private land, both overgrazed and overgrown, with retrievable oak savanna. Much of this land, especially low productivity sites, could be restored within a decade or two simply by tree thinning, brushing, and burning. Well-drained, rich soil sites will require more work and time to restore. Some plant reintroduction may be necessary, but much can be accomplished with fire alone. Light grazing may also have potential as a savanna management tool and as a means of maintaining the open habitat required by many savanna vertebrates. Grazing, however, should not be considered the best management tool for most savanna plants, although some may do well under light grazing.

Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

The recovery potential of oak savanna in Wisconsin is substantial.

1. Develop an education and awareness program to enhance public and professional appreciation of what oak savanna is, its past prevalence, its rapid decline and current rarity, and its management needs. Because of the current rarity and long-time absence of oak savanna on the landscape, an education program is greatly needed for developing support for its recovery and maintenance. The Department's Bureau of Parks and Recreation and the Bureau of Information and Education should play a major role in this effort.

2. Develop a policy on prescribed burning that recognizes the dependence of some ecosystems, including oak savanna, on fire and examines the resources and staff support necessary to effectively and safely use fire to manage these fire-dependent communities. In addition, air quality standards and policies within the Division of Environmental Quality will need to be clarified.

3. Pursue, as a high priority, protection and maintenance of all high-quality remnants (i.e., with high savanna species richness and community integrity) and mildly degraded sites with high recovery potential. Small, high-quality sites should not be ignored, for they are probably the last refuge for many of the savanna plants, insects, and soil microflora and microfauna. Sites as small as a few acres may be contributing substantially to the genetic variation and survival of many species. This is a critical prerequisite to the success of Action 5, below.

Fire is an essential component of savanna ecosystems. To simulate wild fire, managers use prescribed burning as an important tool in restoration of oak openings and other fire-dependent communities. *Photo from Department State Natural Area Files.*

Small, high-quality sites should not be ignored, for they are probably the last refuge for many of the savanna plants, insects, and soil microflora and microfauna.

4. Provide buffer lands to these small, high-quality sites. Buffer lands are needed if remnant oak savannas are to hang on to the species they have retained through 150 years of continual decline. Buffer lands provide remnants with protection against the negative impacts of external influences and stochastic events and provide space into which the community can expand and rebuild. Buffer lands should be restored with communities that are compatible with the remnants.

5. Pursue recovery and restoration efforts on as large, varied, and intact tracts as are available. There should be several sites 1,000-5,000 acres or more in size. Habitat fragmentation issues should be considered in selecting candidate sites. Large tracts are needed because of the dynamic nature of oak savanna vegetation, due to the shifting mosaic of sun and shade over time. The larger and more varied the restoration area, the greater the likelihood that the savanna community and its associated species will be able to maintain themselves in the long run.

6. Just what total recovery/restoration acreage goal in the state would ensure the long-term survival of the oak savanna community is unknown. Two to three percent (110,000-165,000 acres) of the original acreage may be a reasonable target. This goal, of course, would include both public and private lands. Whatever the final acreage goal, it should include representation of a variety of soil and topographic types as well as geographic locations. Based on the historical range of the community, distribution of the acreage goal within Department Districts should be approximately as follows:

Southern District	45%
Western District	32%
Southeast District	14%
Lake Michigan District	7%
North Central District	2%

   To reach these recovery/restoration acreage goals, some acquisition and protection of private land will be needed, but only for a limited number of high-quality sites. Much can be done for oak savanna in Wisconsin without new land acquisition. Many opportunities exist for recovery on land already managed by the Department, especially within state parks and wildlife areas. For example, the Kettle Moraine State Forest-Southern Unit region is an area with recovery potential on a large scale, and the Department's Southern District Headquarters grounds are a small but highly visible site with exceptional educational potential. There are also opportunities to encourage management for savanna, or at least components of it, on private lands through tax incentives, educational programs, and the offering of technical advice, assistance, and partnerships. The Habitat Restoration Areas component of the Wisconsin Stewardship Program may also provide some opportunities for regaining oak savanna.

> Many opportunities exist for recovery on land already managed by the Department, especially within state parks and wildlife areas.

7. Conduct research on oak savanna and related oak woodland ecosystems regarding plant community association and classification, effects of management on maintenance and recovery, and status of rare species and remnants.

8. Become an active partner in the Midwest Savanna Ecosystem Recovery Plan to be proposed by the U.S. Environmental Protection Agency. The plan will include recommendations on research, inventory, management, and protection of Midwest savannas. This plan was first

discussed at the Midwest Oak Savanna Conference held in Chicago (February 18-20, 1993), organized by the Illinois Chapter of The Nature Conservancy, the U.S. Environmental Protection Agency Region 5, and the College of Natural Resources, UW-Stevens Point.

9. Encourage the establishment of sufficient sources of seeds and plant material using local genotypes of oak savanna species.

Case Study

Kettle Moraine Oak Opening: Natural Community Protection and Restoration through Master Planning

Contributed by Mark Martin, Randy Hoffman, and Signe Holtz.

The Natural Resources Board approved the master plan for the Kettle Moraine State Forest in 1991 after a long planning process that included a Department task force, a vegetation management committee, a citizen's advisory committee, various resource management specialists, citizens, and other organized groups. The state forest, as its name indicates, lies in the kettle moraine area of southeastern Wisconsin. Along the moraines in the Southern Unit are oak openings and oak woodland, and in the kettles and lowlands lie vast wetlands of prairie, fen, and sedge meadow. Dry prairies cover the southern- and western-facing hillsides. The Southern Unit also contains many populations of rare species (listed as endangered or threatened or of special concern), including 11 bird species, 18 plant species, seven insect species, and two mammal species.

As the planning process progressed, it became apparent that this property could contribute greatly to the protection of Wisconsin's natural heritage because it harbored degraded oak openings, one of the rarest natural communities in the state. As the largest block of public land in the southeast with more than 29,000 acres in the project boundary, it would also be one of the only opportunities in southeastern Wisconsin to restore an oak opening at the scale that it had occurred in the past. There were several sites with great restoration potential because of the existing tree structure and because surrounding public land ownership gave the Department the ability to manage effectively using prescribed burning. Out of this discussion came the proposal to create the Kettle Moraine Oak Opening, which would include the existing Blue Springs Oak Opening and three parts of the Messinger Dry Prairie and Savanna Preserve.

The proposal became part of the master plan and since then the Department has been preparing the site for larger prescribed burns. First, crews have been removing buckthorn and honeysuckle, both non-native species, by cutting and using spot-herbicides. Second, they have burned small prairie patches to stimulate existing prairie plants to produce more seeds. This seed production, combined with the removal of the non-native shrub layer, should allow prairie to expand more easily across the site.

Soon, the Department will burn much larger parts of the oak opening: 100-700 acres at a time, and at fairly short intervals (two or three years). As Randy Hoffman of the Department's Bureau of Endangered Resources explains, "This is a 100-year work-in-progress." As time goes by, the Department will examine the results, monitor restoration research, and change management as needed.

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CHAPTER 7

Oak and Pine Barrens Communities

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Description

The oak and pine barrens communities of Wisconsin are two of the four types of savanna described by Curtis (1959). Oak opening is discussed in the previous chapter. Cedar glade, a very specialized savanna, is not discussed in this report. In this chapter the other two types of savanna, the closely related oak and pine barrens, are covered along with bracken grasslands.

"Barrens" are plant communities that occur on sandy soils and are dominated by grasses, low shrubs, small trees, and scattered large trees. Curtis (1959) described these communities as pine barrens in northern and central Wisconsin and as oak barrens in southern and west-central Wisconsin. Because of their dynamic nature and the variability in structural types and species composition, they are difficult to describe and classify. For example, Eric Epstein (Wis. Dep. Nat. Resour., pers. comm.) studied the original land survey notes for the area that is now southern Fort McCoy and found that the surveyor had characterized the vegetation variously as "oak openings," "oak brush," "pine-oak woodland," "pine brush," "oak forest," and "level prairie." Many northern pine barrens are referred to as "brush prairie." This range of names derives from the many forms that barrens have. Prior to Euro-American settlement, the vegetative structure of large barrens landscapes was quite variable and dynamic. Inclusions of variously sized and aged forest stands such as mature red pine, mature oak (bur, red, Hill's, or black), aspen groves, and numerous wetlands were typical of most presettlement pine and oak barrens (Murphy 1931).

One consistent element of all barrens, though, is the dependence of barrens on fire and the major role that fire plays in their dynamics. Fires have burned on Wisconsin barrens for thousands of years. Prior to Euro-American settlement, fires were caused by lightning or were set by Native Americans. Native Americans used fire to maintain game habitat, drive game, and enhance fruit and berry crops. Historically, behavior of fire was greatly influenced by topography and soil factors. Natural wildfires usually produce a complex mosaic of burned and unburned

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patches depending on fire intensity, topography, soil moisture, and local weather (Niemi and Probst, 1990). True savanna (widely scattered large trees over a prairie-like understory) was likely maintained by frequent fires of relatively low intensity. Brush prairie may have been subject to a more erratic fire regime with occasional catastrophic events that reduced the oaks to the grub stage.

Because of this long association with fire, the plants and animals that live on the barrens are adapted to periodic fire. Vogl (1970) states: “The question of whether fire is necessary to maintain northern Wisconsin pine barrens is perhaps not an appropriate question, for all factors including soil type, soil fertility, topography, climate, drought, and fire are inseparably linked and operate together or in chain reactions and cannot be considered individually. Fire is one of the essential ingredients of pine barrens, but the critical factor in determining the presence of barrens among northern pine-hardwoods forests is not so much fire, but the presence of sandy plains; sites with low fertility that lend themselves to droughts and fires of the proper intensities and frequencies to produce a vegetational structure and composition called barrens.” Much still needs to be learned about the relationships between fire and barren structure and composition (Mossman et al. 1991).

Pine barrens . . . are true savannas, in that the dominant plants are grasses, forbs and shrubs, with scattered stands of trees.

Pine Barrens

Curtis (1959) describes pine barrens as follows:

> *These barrens are true savannas, in that the dominant plants are grasses, forbs and shrubs, with a scattered stand of trees. The most usual tree is jack pine, although red pine may be the main species in unusual cases. Hill’s oak is usually present as a grub or as a scattering of larger trees . . . . The outstanding feature of the groundlayer in the pine barrens is the extraordinary development of shrubs. This is . . . far higher than for any other community in Wisconsin. Two of the shrub species, redroot . . . and huckleberry . . . , reach their maximum Wisconsin levels in this community; but the blueberry . . . is of even greater importance . . . . Another shrub which is highly characteristic of the barrens is the sweet fern . . . . The 134 [plant] species found in the barrens are distributed in 48 families, of which these five contain over one-half of the total: Compositae-23.9 per cent, Gramineae-10.4 per cent, Rosaceae-8.2 per cent, Liliaceae-6.7 per cent, and Ericaeae-6.0 per cent . . . . [T]here is no doubt that the immediate cause of a pine barren is fire. In this case, soil and topography are major contributing factors, since it is essential that the fires be repeated at such short intervals as to prevent the active reseeding of jack pine from its serotinal cones.*

This is a typical pine barrens in Florence County. The dominant tree is jack pine with an understory dominated by sweet fern, hazelnut, and sedges. Also found there are species in the heath family and native grasses found on poor soils, such as Kalm’s brome grass and poverty oat grass. *Photo by Eric Epstein.*

Vogl (1964*a*, 1970) studied northern Wisconsin pine barrens and found “the locations of northern Wisconsin pine barrens correlated with the distribution of sandy soils, great forest fires, present fire hazard areas, sites subject to local drought, the last strongholds of prairie grasses, and areas of past farming failures and forest planting difficulties." Vogl found that the pine barrens possess some characteristic plant species even though plant communities vary in different barrens. Prairie-influenced pine barrens in far northwestern and northeastern Wisconsin averaged 26 more plant species than pine barrens in north-central Wisconsin. Prairie plants were present in the far northwest and northeast, but absent in the north-central pine barrens. Shively and Temple (1994) describe pine barrens as an open grassland with scattered trees and shrubs, i.e., a pine savanna. They describe a pine-shrub-grassland ecosystem as a varying mosaic of vegetation structural types that occur on sandy glacial outwash plains, developing and deteriorating in response to periodic disturbance.

Prior to Euro-American settlement many pine barrens were diverse. Some resembled a pine savanna with mature red pine occurring in densities of two to eight trees per acre and an average diameter at breast height (dbh) of 13 inches. Early logging eliminated the mature trees. Severe, repeated fires, along with more cutting and land-clearing, removed the seedlings and remaining red pine seed sources.

Several specific Wisconsin barrens sites were described historically. Fassett (1944) described barrens near the Brule River in Douglas County in 1854 as a region of frequent fires, covered with small jack pine and occasional large scattered red pine. Oak trees and oak brush often accompanied and sometimes replaced the jack pines. Matthiae and Stearns (1978) and Vora (1993) recount historical records describing the Moquah Barrens in Bayfield County in 1858 as a diverse landscape with openings of various sizes, areas with scattered trees, some open forest and some closed-canopy forests about 60 years old. Vogl (1964*b*) recounts historical descriptions of Crex Meadows in Burnett County in 1853 as a jack pine—scrub oak—prairie savanna. The surveyors' records refer to a jack pine savanna consisting of large, open-grown jack pines scattered across a level to rolling landscape with some scattered red pine and scattered areas of oak bushes. The Dunbar Barrens occur in Marinette County. Although we have no 19th-century description of this site, in the 1960s LeRoy Lintereur (Wis. Dep. Nat. Resour., retired, pers. comm.) found various species of reindeer moss present, with sedges more abundant than grasses. Sand willow and sand cherry were common. Barnes (1974) quotes the description of the northwestern Wisconsin pine and oak barrens published by E. T. Sweet in 1875: "The trees are either scrub-pine or black-jack oak, averaging in diameter about three or four inches and in height not over fifteen feet. In some places, as in the sand hills of the barrens, the trees are at considerable distances from each other, and in other places the little scrub pines, not over two inches in diameter, are so close together as to constitute a nearly impenetrable thicket. On the sides of the barrens, and in low places, quite large groves of norway pine are frequently found."

Oak Barrens

Curtis (1959) describes oak barrens as follows:

> *Several of the early writers mentioned that the bur oaks and white oaks of the heavy soil openings were replaced by black oaks on the sandy areas, but few detailed descriptions of the type exist. Most of the comments refer to the jack pine barrens found on similar sites in the north. Actually the two types are closely related and intermediate mixtures of both oak and pine are widespread in central and northwestern counties. For purposes of this discussion, oak barrens are considered to be those savannas which have black oak or Hill's oak as their most prominent tree and in which jack pine is absent. As such, they are located entirely in the prairie-forest province south of the tension zone. They are prominent on the outwash-filled valleys of the Wisconsin River from Portage to Arena and the Sugar River in Green County, and on the sandy uplands of Marquette and Waushara counties . . . . The origin of the scrub oak savannas is*

the same as that of the oak openings—degradation of prior forests by fire. Maintenance is also by fire, but with the major difference that the tree component is likely to be completely destroyed at rather frequent intervals.

Finley (1976) states: "Some minor portions of the oak region were in neither oak forest nor oak openings. These were the so-called oak barrens where thin stands of scrubby dwarf oak grew on sandy soils. The sparse growth appears to have been due more to the sandy earth material rather than to climatic influences. The uniqueness of the oak barrens resulted from the open spacing of the trees, the small size of the trees, and the otherwise barren character of the surface. This type of vegetation occurred in small fragmented areas in Eau Claire County, eastern Dunn County, and western Chippewa County."

Barnes (1974) found the oak-pine barrens of Eau Claire County very heterogeneous, with the oak and pine generally forming a mosaic of separate stands of various sizes. The Eau Claire County barrens were probably open areas that contained few trees interspersed with rather dense stands of oak and pine.

Habeck (1959) describes a general picture of the vegetation in Juneau and Jackson counties prior to the turn of the century provided by Filibert Roth in 1898: "Roth stated that much of the central Wisconsin sand plains was covered with scrub oak and jack pine openings, with some portions covered with dense groves of jack pine and a few islands of mature red pine and white pine. Mesic upland hardwood forests were apparently not present or not common enough to draw Roth's attention. Roth further stated that there were extensive bare wastes which he believed were the result of logging and burning."

Oak barrens are considered to be those savannas which have black oak or Hill's oak as their most prominent tree and in which jack pine is absent. As such, they are located entirely in the prairie-forest province south of the tension zone.

This barrens has large, open-grown oaks with a sand-prairie understory including such species as lupine, little bluestem grass, and June grass. If not subjected to fire, oak barrens over time become more like southern dry forest. Notice in the foreground the oak seedlings and saplings in the understory which over time may form a more closed canopy. *Photo by Cathy Bleser.*

Holtz (1985) described a black oak barrens in Sauk County as a dynamic community of trees, shrubs, and understory plants that is maintained through periodic fire. After decades without fire, many understory plant species persist as dwarfed, nonreproducing culms and rhizomes or as old seeds. If remnant barrens plants are on site, former barrens can be restored by a combination of cutting to open the canopy and prescribed burning.

Bracken Grasslands

Curtis (1959), Vogl (1964*b*), and Levy (1970) identified bracken grasslands, sometimes called frost pockets, as a distinct vegetation type. Bracken grasslands are large forest openings dominated by various grasses and bracken fern. Probably some of the original pine barrens of northern Wisconsin included bracken grasslands. Bracken grasslands occur on a variety of soils, from fine sands to loams. Bracken grasslands on loamy soils are thought to originate after clearcutting and intense wildfire. However, some bracken grasslands on sandy soils may be natural communities of the same nature and origin as the southern Wisconsin prairies (Curtis 1959).

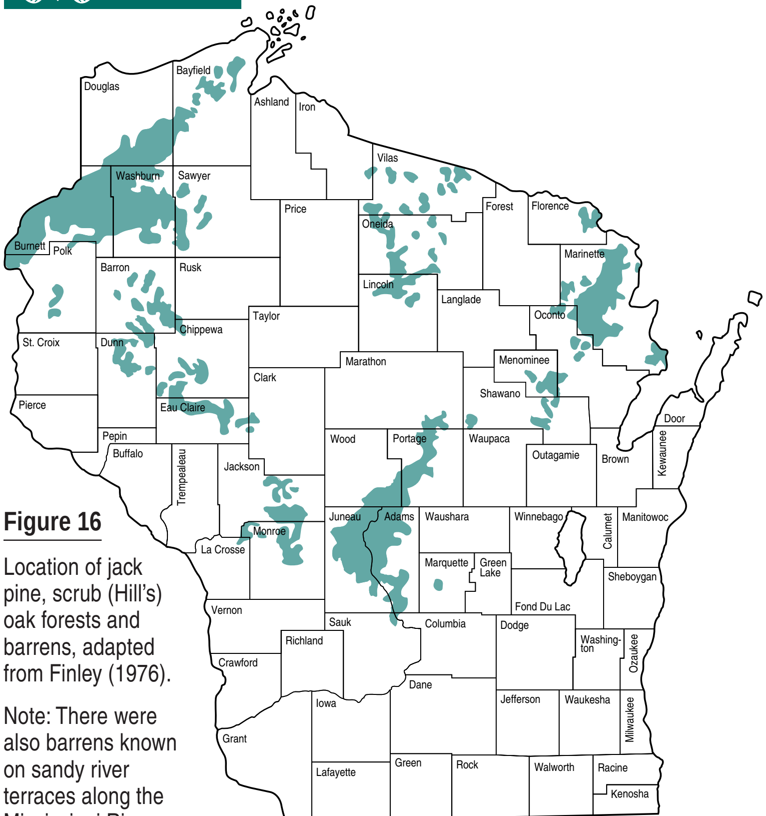

Figure 16

Location of jack pine, scrub (Hill's) oak forests and barrens, adapted from Finley (1976).

Note: There were also barrens known on sandy river terraces along the Mississippi River, Lower Wisconsin River, Chippewa River, and Black River.

Levy (1970) recognized two forms of bracken grassland. One form is found on loamy soils and is characterized by exotic plants such as quack grass, Kentucky bluegrass, and Canada thistle. The other form is found on sandy soils and is characterized by blueberries and sweet fern. Exotic plants form a high content in both forms.

Vogl (1964*b*) and McCaffery and Creed (1969) concluded that several factors operate in combination to maintain bracken grasslands. Tree reproduction is limited by frost, animal browsing, plant allelopathy, dense sod, and a dense bracken fern canopy cover.

Pine Barrens are also found along the lower Wisconsin River and other rivers in the Driftless Area. This barrens in Richland County along the Wisconsin River has large jack pine and scrub oak with an understory of sedges, prickly pear, blueberry, and some typical prairie species. *Photo by Signe Holtz.*

Status

Past

Pine barrens originally covered 2.3 million acres, or 7% of Wisconsin's presettlement landscape (Figs. 10 and 16). Oak barrens covered 1.8 million acres, or 5% of the presettlement landscape. Mossman et al. (1991) state: "Prior to settlement, barrens habitats were widespread in Wisconsin, always associated with coarse-textured sandy or gravelly soils. The most extensive barrens were in large areas of sandy glacial outwash, or in the sandy beds of extinct glacial lakes, but they also occurred on river terraces, old dune systems, gravelly moraine, and sandspits. Geographically, areas of extensive barrens were concentrated in northeastern, north-central, northwestern and central Wisconsin. They were also common on the extensive outwash terraces along the Lower Wisconsin, Lower Chippewa and Mississippi Rivers. In general, trees occurred in low density, usually as scattered individuals or in small groves, punctuating an open grassy landscape that was often dotted with deciduous brush. Where outwash was pitted, the topography was more pronounced and varied and lakes and wetlands were sometimes frequent. In such areas, the pattern of vegetation was likely to be a mosaic of open prairie-like areas, brush, savanna, and occasional stands of deciduous, coniferous or mixed forest. The interplay of topographic and edaphic factors strongly influenced the behavior and effects of the primary disturbance factor affecting the barrens—fire—and is responsible for much of the structural, and compositional variability demonstrated by this community."

Because of the dynamic nature of barrens and their inherent variability, there is a general lack of knowledge of the exact structure of barrens. Some aspects of barrens that were described by early European explorers appear to have disappeared from today's landscape. For example, some pine barrens were described as having large mature trees, either as widely scattered individuals or dense clusters of mature trees. Pine savannas with scattered large trees are extremely rare.

Present

Eric Epstein (Wis. Dep. Nat. Resour., pers. comm.) summarized Natural Heritage Inventory data and identified approximately 10,000 acres of pine and oak barrens remaining at 65 sites (Table 5). These figures do not include all of the pine and oak barrens in Wisconsin. The most significant omissions are portions of the large managed barrens on county, state, and federal lands in northwestern Wisconsin and on the Necedah National Wildlife Refuge in central Wisconsin. Some of the managed barrens are reclaimed forest or abandoned farmland with reduced floristic compositions. The 1,432 acres of southern oak barrens at 20 sites is a fairly accurate estimate.

Because of the dynamic nature of barrens and their inherent variability, there is a general lack of knowledge of the exact structure of barrens. Some aspects of barrens that were described by early European explorers appear to have disappeared from today's landscape.

The Natural Heritage Inventory lists pine barrens as G3 (very rare and local throughout its range or found locally) and oak barrens as G2 (imperiled globally because of rarity) (see Table 1). Most remaining pine and oak barrens exist as small, isolated fragments on about a dozen state or federal managed areas. Most of these fragments are too small and isolated to ensure long-term viability of all their characteristic native plants and animals. For example, a minimum of 10,000 acres of pine barrens has been recommended for long-term survival of an isolated sharp-tailed grouse population with limited hunting (Temple 1992).

This is the most intact red pine savanna in Wisconsin. Located on the Lake Superior shoreline of one of the Apostle Islands, this site has an understory of common juniper, native grasses and sedges, blueberry, false heather, and sand cherry. The groundlayer includes species that are characteristic of dune and lakeshore communities and many species not found in Wisconsin except near the Lake Superior shore. *Photo by Signe Holtz.*

Vegetation

Pine Barrens. Most of northern Wisconsin's pine barrens have succeeded to northern dry forest. Recently, Kotar et al. (1988) published a natural classification system for northern Wisconsin. This system utilizes interpretation of natural vegetation along soil moisture and nutrient gradients with emphasis on understory species. The following habitat types from the Kotar system can be used to describe the present status of former barrens in northern Wisconsin.

Table 5

Remaining acreage of intact Wisconsin pine and oak barrens, 1992, as listed in DNR's Wisconsin Natural Areas Inventory.

	Acreage		
Classification	Pine Barrens	Oak Barrens	Total
Undisturbed	3,952	420	4,372
Moderately disturbed	3,421	280	3,701
Disturbed	1,205	732	1,937
Total	8,578 (45 sites)	1,432 (20 sites)	10,010 (65 sites)

In central and southern Wisconsin counties the former barrens communities now support extensive pine plantations, irrigation agriculture, or a natural growth of dry oak forest.

The pin oak/wintergreen-New Jersey tea forest habitat type occurs in Burnett, Washburn, and Douglas counties. The dominant landform is pitted outwash; the dominant soil is dry, nutrient-poor sand. The following species are diagnostic: New Jersey tea, sweet fern, wintergreen, bush honeysuckle, cow-wheat, trailing arbutus, bearberry, and sessile bellwort. Within this general habitat type the common forest types are jack pine, scrub oak forests and barrens, jack pine-pin oak, pin oak, aspen, and red pine.

The red oak-red maple/trailing arbutus forest habitat type which occurred in the former barrens in Marinette, Menominee, Oconto, Florence, Lincoln, Oneida, and Vilas counties has been replaced by forest cover of jack pine, red pine, aspen, and red oak-red maple. Understory vegetation includes bracken fern, grasses, sedges, blueberry, wintergreen, and trailing arbutus. Low shrubs are more common than tall shrubs. Dry, nutrient-poor soils predominate.

A white oak-pin oak/lead plant forest habitat type occurs in extreme northwestern Polk County and southwestern Burnett County. This habitat type appears to represent a prairie-forest transition. Common forest cover types include jack pine, scrub oak forests, and barrens.

Some barrens communities were located on the red maple-red oak/low sweet blueberry habitat type, which occurred in the former barrens of north-central and northeastern Wisconsin. The current common forest cover types occurring on this habitat type include aspen-white birch, aspen-red oak, aspen-pines, jack pine, red pine, white pine, red oak, red oak-red maple, and balsam fir-white spruce. This habitat type has more moisture, is more mesic, and quickly succeeds to closed canopy forest.

Most remaining pine and oak barrens exist as small, isolated fragments—too small and isolated to ensure long-term viability of all component plant and animal species. It is estimated that the population of one species, sharp-tailed grouse, shown here in a picture taken in 1942 in Wood County, would require a minimum of 10,000 acres of pine barrens for long-term survival with limited hunting. *Photo by Dorothy Cassoday.*

Oak Barrens. In central and southern Wisconsin counties the former barrens communities now support extensive pine plantations, irrigation agriculture, or a natural growth of dry oak forest. In relatively undisturbed forests, prairie grasses and forbs reappear if the forest cover is clearcut and the logging slash burned (Holtz 1985).

Bracken Grasslands. In northern Wisconsin the land area in bracken grasslands has significantly declined. Fire control, tree planting, and aspen sprouting following clearcutting of adjacent forest resulted in conversion of most bracken grasslands to balsam fir, white pine, and aspen. About 1% to 2% of the northern public forest lands exist in forest openings or bracken grassland. A white-tailed deer habitat maintenance program undertaken by the Department and the U.S.D.A. Forest Service has maintained these small, scattered bracken grasslands.

Animals

Barrens are inhabited by animals that require open, brushy habitats. Large, open barrens are critical habitat for sharp-tailed grouse (Hamerstrom and Hamerstrom 1952, Gregg 1987); barrens large enough to sustain a viable population of sharptails will also sustain populations of other plants and animals common to large, open, brushy habitats. The particular structure of each barrens will dictate the particular complement of species present and their relative abundance.

Jackson (1961) and Hamilton and Whitaker (1979) report that the following mammals find preferred habitat in barrens: thirteen-lined ground squirrel, plains pocket gopher, prairie deer mouse, coyote, badger, white-tailed deer, and striped skunk.

Elk may have been another important species on barrens in presettlement times. Pierre Radisson described elk as fairly abundant in parts of northwestern Wisconsin in 1658-60 (Seno 1985), but Schorger (1954) gives only one literature reference for elk in northwestern Wisconsin in the 1800s (in the Superior area). Apparently elk were more abundant in the oak savannas, forest edge, and open woodlands of southern and central Wisconsin (Schorger 1954).

Faanes (1981), Hoffman and Mossman (1990), and Mossman et al. (1991) described the birds of barrens and young pine forest. Mossman et al. (1991) describe the barrens bird community:

> *The barrens is a tenuous community pulled in opposing directions by fire/frost and succession. The barrens avifauna responds to the variety and pattern of structures and dominant plant forms in this dynamic community, and can be seen as a variable combination of elements from related communities such as dry prairie (Sample and Hoffman 1989), xeric pine and hardwood forest (Hoffman and Mossman 1990) . . . . Yet barrens also represent a real natural community with unique characteristics, and has undoubtedly been a major component of the upper Midwest landscape for centuries; thus it is not surprising that several bird species appear to be especially adapted to it.*
>
> *Altogether, the most common and regular species of Wisconsin pine and oak barrens are blue jay, common yellowthroat, rufous-sided towhee, brown-headed cowbird, and the chipping, clay-colored, field, and vesper sparrows. Other characteristic species that are found here equally or more commonly than perhaps in any other native Wisconsin community include sharp-tailed grouse, upland sandpiper, northern flicker, eastern kingbird, eastern bluebird, brown thrasher, Tennessee warbler, lark sparrow, Brewer's blackbird and American goldfinch.*
>
> *Open barrens are characterized by dry sand prairie birds, most of which tolerate or prefer some low (<1 m tall [3.1 ft]) woody vegetation: chipping, clay-colored, field, vesper, grasshopper and song sparrows, upland sandpiper, brown thrasher, bobolink, western meadowlark, Brewer's blackbird, brown-headed cowbird and American goldfinch. Common nighthawk is another species common to open barrens and dry sand prairie. The relatively high abundance of Brewer's blackbirds in open barrens is partly a consequence of its common association with recently burned sites and dead, fallen wood. In some cases, song sparrows also seem attracted to recently burned areas where remain charred stems of shrubs and oak grubs. Nearly all of the species of Wisconsin's dry prairies are well represented in open or other types of barrens. Because these barrens are generally larger, and in many cases more manageable than southern Wisconsin's isolated, dry prairie relics, they serve an important role in maintaining this natural association of breeding-bird species, especially for those such as upland sandpiper that require large tracts.*

Vogt (1981) found Cope's gray treefrog, American toad, five-lined skink, hognose snake, green snake and bullsnake common in Wisconsin pine and oak barrens. James Hoefler (Wis. Dep. Nat. Resour., pers. comm.) reports prairie skink common in northwestern barrens. Eric Epstein (Wis. Dep. Nat. Resour., pers. comm.) reports the six-lined racerunner and slender glass lizard present in west-central Wisconsin pine and oak barrens. Barrens habitats may be important nesting sites for aquatic turtle species that lay their eggs in upland, often sandy soils (Robert Hay, Wis. Dep. Nat. Resour., pers. comm.).

In general, little is known about the invertebrates that occupy the barrens community or the ecological function they fulfill. An exception is the butterfly and moth fauna, which has been extensively studied by Ferge (1990). Based on his publication and his personal records, we were able to compile a list of butterflies and moths of barrens habitats (Table 6). Endan-

Prairie fameflower (*Talinum rugospermum*) occurs in sand prairies within barrens complexes in central and west central Wisconsin. This individual is growing on sand that has eroded from a sandy rock outcrop. *Photo by Thomas A. Meyer.*

gered, threatened, and other rare species are covered in more detail in the following paragraphs.

Rare Species

Endangered Species. Larvae of the Karner blue butterfly, a federally endangered species found primarily in northwestern and central Wisconsin, feed only on lupine. Midwestern populations of the wide-ranging northern blue butterfly are restricted by the distribution of its sole larval food plant, the dwarf bilberry. These species are known from very limited locations in central and northeastern Wisconsin (Ebner 1970). The phlox moth is found in Eau Claire County. The sand violet is found in west-central Wisconsin pine barrens. The rough white lettuce, phlox moth, and slender glass lizard have recent records at Fort McCoy (Eric Epstein, Wis. Dep. Nat. Resour., pers. comm.). Several singing males of the federally endangered Kirtland's warbler have been located in west-central and northwestern Wisconsin pine barrens.

Threatened Species. The frosted elfin butterfly is restricted to pine and oak barrens that contain large populations of lupine and false wild indigo (larval food plants). The wooly milkweed has historical records from sandy barrens near Necedah National Wildlife Refuge and other central Wisconsin oak barrens and sand prairies. The brittle prickly pear is found in oak barrens, dry cliffs, and sand prairies mostly in central and west-central Wisconsin.

Table 6

Butterflies and moths of barrens habitats.*

Species	Range**	Flight	Status**	Larval Host
Moths				
Saturniidae—Giant Silkmoths				
Hemileuca nevadnesis (Nevada buck moth)	Burnett & Douglas Co.	Sept	local	prairie willow, poplar
Sphingedae—Sphinx Moths				
Hemaris gracilis (graceful clearwing)	N,C	May-Jun	rare	blueberry
Notodontidae—Prominents				
Hyparpax aurora (pink prominent)	C	Jun	local	oak
Arctiidae—Tiger Moths				
Grammia celia	C	May-Jun	local	unknown
Pygarctia spraguei (Sprague's pygarctia)	C	Jun	local	*Euphorbia*
Noctuidae—Owlet or Noctuid Moths				
Schinia indiana phlox flower moth	Eau Claire Co.	Jun	**Endangered**	*Phlox pilosa*
Heliothis borealis	N,C	May	local	unknown

Species	Range**	Flight	Status**	Larval Host
Butterflies				
Hesperiidae—Skippers				
Erynnis brizo (sleepy dusky wing)	State	May-Jun	M	oak
Erynnis juvenalis (Juvenal's dusky wing)	State	May-Jun	4	oak
Erynnis persius (Persius dusky wing)	C	May	3	lupine
Hesperia comma laurentina (Laurentian skipper)	N	Jul	3	grasses
Hesperia leonardus leonardus (Leonard's skipper)	N,C	Aug	M	grasses
Hesperia Metea (cobweb skipper)	N,C	May	M	grasses
Hesperia sassacus (Indian skipper)	N,C	Jun	M	grasses
Atrytoropsis hianna (dusted skipper)	W,C	May-Jun	M	*Andropogon*
Amblyscirtes vialis (roadside skipper)	N,W	May-Jul	M	grasses
Pieridae—Whites and Sulphurs				
Euchloe olympia (Olympian marble)	State	May	M	rock cress
Colias interior (pink edged sulpher)	N,C	Jun	M	blueberry
Lycaenidae—Harvesters, Coppers, Hairstreaks and Blues				
Lycaena phlaeas americana (American copper)	State	May-Aug	4	rumex
Harkenclenus titus (coral hairstreak)	State	Jul	4	cherry
Satrium edwardsii (Edward's hairstreak)	W,E,C	Jul	M	oak
Incisalia augustinus (brown elfin)	N,C	May	M	blueberry
Incisalia polia (hoary elfin)	N,C	May	M	blueberry
Incisalia irus (frosted elfin)	C	May	3	lupine
Incisalia henrici (Henry's elfin)	N,C	May	3	blueberry?
Incisalia niphon clarki (pine elfin)	N,C	May	M	jack pine
Everes amyntula (western tailed blue)	N	May	3	vetch?
Glaucopsyche lygdamus couperi (silvery blue)	State	May	M	lathyrus
Lycaeidesidas nabokovi (northern blue)	N	Jul	**Endangered**	dwarf bilberry
Lycaeides melissa samuelis (karner blue)	C	May-Aug	**Endangered**	lupine
Nymphalidae—Brush-Footed Butterflies				
Charidryas gorgone carlota (Gorgone checkerspot)	W,E,C	May-Sep	M	*Helianthus*
Phyciodes batesii (tawny crescent)	N,C	Jun	M	aster
Satyridae—Satyrs and Wood Nymphs				
Oeneis chryxus strigulosa (chryxus arctic)	N	May	3	grasses

* From Ferge 1990, with additional information from 8 April 1991 correspondence from Leslie Ferge to the author.

** Codes

N = Northern Highland south to Tension Zone

C = Central Sands and Burnett County

W = Driftless Area and Western Wisconsin

E = Eastern Ridges and Lowlands

Status:
3 = Resident, but rare and/or local in occurrence
4 = Common or widespread
M = Not really rare, but not widespread or numerous enough to regard as common.

Without active restoration and management the barrens community will probably disappear from all but a few large public land areas and a handful of small, isolated managed areas.

Species of Special Concern. Ternate grape fern, common hairgrass, and possibly Hookers' orchid may occur on or near barrens in pockets of northern dry forest. Prairie fameflower occurs in sand prairies within barrens complexes in central and west-central counties. In addition, there are some Great Plains plant species that reach their eastern range limits in the Polk, Douglas, and Burnett county barrens (Robert Read, Wis. Dep. Nat. Resour., pers. comm.).

Projected

Without active restoration and management the barrens community will probably disappear from all but a few large public land areas and a handful of small, isolated managed areas.

Actions Causing Concern

Since Euro-American settlement, the pine and oak barrens communities have been reduced to small scattered parcels with a simplified vegetative structure and a reduced composition of plants and animals. Control of wildfire, forest succession, pine plantation development, and agricultural development have all worked to bring the barrens communities to their current rarity.

Some citizens question the necessity and value of timber cutting and prescribed burning, management techniques used to restore barrens. Air quality standards applicable to prescribed burning need to be clarified. Some land managers and citizens consider the barrens landscape as, indeed, barren or worthless. The great habitat values and aesthetic appeal of barrens remain largely unrecognized.

Socio-Economic Issues

Landowners and land managers often see barrens management as reducing their ability to grow commercial trees. Some people find the barrens an exceptionally aesthetic landscape where native plants and animals have adapted to the very poor site nutrient quality and open character. Wisconsin's former barrens landscapes could be used by citizens for a variety of products and purposes. These include wood fiber, food, game animals (including sharp-tailed grouse), and native plant and animal populations. A combination would best meet the overall needs of Wisconsin's citizens.

Potential for Community Restoration

Mossman et al. (1991) state: "Wisconsin's oak and pine barrens evolved in a dynamic landscape governed largely by the forces of succession, fire and frost. Variety of this landscape was imparted by the variable influences of climate, topography, soils, moisture regimes and fire barriers. Despite the neglect and abuse that most barrens have undergone since settlement, this is one of our most resilient natural communities, and it will respond to careful management by controlled [prescribed] burns and cutting. Moreover, its economic land value is generally low, and comparatively little has been permanently converted to other uses. Perhaps for no other native community are the opportunities for large-scale restoration so great."

Despite the neglect and abuse that most barrens have undergone since settlement, this is one of our most resilient natural communities, and it will respond to careful management by controlled [prescribed] burns and cutting.

Department wildlife areas in northwestern Wisconsin, the Necedah National Wildlife Refuge, and the Chequamegon National Forest's Moquah Barrens form the nucleus for large landscape-scale barrens management. Barrens can be restored through cutting and prescribed fire (Holtz 1985, Vora 1993, U.S. Fish and Wildlife Service 1994) or through a combination of cutting, limited herbicide use, and prescribed fire (Paul Kooiker and Mike Zeckmeister, Wis. Dep. Nat. Resour., pers. comm.).

Shively and Temple (1994) describe a pine-shrub grassland restoration plan with goals of increasing area and decreasing fragmentation of barrens, restoring the full natural range of variation in structure and composition of patch types in barrens landscapes, and obtaining statewide support and involvement of state residents.

Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

1. Restore several large pine and oak barrens communities. These actions may include the following:

   - ▲ Continue development of Fish Lake Wildlife Area in Burnett County to establish large barrens and savanna.

   - ▲ Continue management of Crex Meadows and Kohler Peet areas. Explore opportunities to work with Burnett County to manage county forest land between the two areas for a connecting corridor of ecologically functional barrens habitat.

   - ▲ Continue restoration and expansion of barrens habitat within the approved Namekagon Barrens Wildlife Area. The goal will be restoration and maintenance of an extensive barrens landscape that includes various barrens types.

   - ▲ Work with Douglas County to expand and continue development of Douglas County Wildlife Area. Expansion could include about one section (640 acres) of additional land.

   - ▲ Encourage the Chequamegon National Forest to continue to enlarge Moquah Barrens. Support creation of a large barrens landscape around the Moquah Barrens Wildlife Area including old-growth jack pine, scattered red pine, frost pockets, seepage lakes, and small wetlands.

   - ▲ Continue restoration and management of a large oak barrens at Necedah National Wildlife Refuge.

   - ▲ Work with local officials in Adams and Juneau counties and Monroe and Jackson counties to explore the opportunity for restoration of large barrens. Because of its geographic location, this area supports a far greater diversity of barrens plants and animals than other areas of the state, including more threatened and endangered species.

2. Restore smaller barrens to conserve plant and animal species diversity. For example,

   - ▲ Continue the development of suitable barrens habitat on Amsterdam Sloughs Wildlife Area.

   - ▲ Manage the Dunbar Wildlife Area to restore barrens.

- ▲ Manage the Spread Eagle Wildlife Area to restore a barrens landscape that includes wetlands, Pine River shoreline, and seepage lakes.

- ▲ Continue restoration and management of oak barrens at the Sandhill Wildlife Area.

- ▲ Work with the Nicolet National Forest to explore opportunities for restoration of barrens in the Lakewood District.

- ▲ Work with federal Department of Defense officials to restore an oak barrens at Fort McCoy, Monroe County.

- ▲ Protect and manage scattered small barrens to enhance populations of locally rare plant and animal species. Included here are the 1/4-mile-wide fire breaks maintained on state and county forests in northwestern Wisconsin and tracts along the Lower Wisconsin River.

- ▲ Maintain and restore the scattered bracken grasslands on public lands in northern Wisconsin.

3. Restore and manage pine and oak barrens with a variety of structures including brush prairie, pine savanna, older jack pine stands, and mature red pine pockets. The barrens landscape should also contain grassland, frost pockets, wetlands, and lakes. This landscape will best meet the needs of a wide variety of barrens plants and animals.

4. Maximize the connectivity of pine and oak barrens restorations using techniques that are found to be effective by current conservation research. These may include the establishment of corridors of open land between barrens habitats. These corridors need to be carefully planned to avoid unintended effects such as species traps and the introduction of exotic species. Utility rights-of-way, railroads, or short rotation timber harvest could be used as corridors.

5. Develop an education and awareness program to increase public and professional knowledge and appreciation of what barrens are, their past prevalence, their current rarity, and their management needs. Because of the barrens rarity, an education program is needed to develop support for restoration and management of barrens.

6. Develop a policy on prescribed burning that recognizes the dependence of some ecosystems, including barrens, on fire and that examines the resources and staff support necessary to effectively and safely use fire to manage these fire-dependent communities. In addition, air quality standards and policies within the Department's Division of Environmental Quality will need to be clarified.

7. Gather more information on the structure and composition of barrens that existed at various times in the past, drawing on a variety of sources, to describe the full range of variability of these communities.

Case Study

HABITAT CONSERVATION PLANNING: SPECIES PROTECTION THROUGH ECOSYSTEM MANAGEMENT

Contributed by Cathy Bleser, Darrell Zastrow, and Signe Holtz.

Since the federal government listed the Karner blue butterfly as federally endangered in 1992, the Department has been working on its protection and recovery. At present, a Rangewide Federal Recovery Plan is being developed, and in Wisconsin, where the Karner blue butterfly is most abundant and widespread, a Habitat Conservation Plan (HCP) is underway. A HCP is required for any incidental taking of the insect to be permitted by the U.S. Fish and Wildlife Service. This HCP approach calls for working with an extensive group of public agencies, private businesses, and nonprofit conservation organizations to develop a plan for conservation of Karner blue habitat. Although the butterfly lives in several different natural communities that contain its larval food plant, lupine, in Wisconsin it is found most often on barrens. In addition, barrens are home to many other state and federally listed species such as phlox moth, massasauga rattlesnake, prairie fameflower, and frosted elfin butterfly.

The Karner blue butterfly, a federally endangered species, occurs most often in Wisconsin on barrens. Here it rests on black-eyed Susan (*Rudbeckia hirta*) in Eau Claire County. *Photo by Eric Epstein.*

Although the Karner blue butterfly is the catalyst for the planning process, the Department will expand the focus to the barrens ecosystem on Department lands and encourage ecosystem considerations across the extensive range of the butterfly in Wisconsin. It has been found on public and private land across central and northwestern Wisconsin. In order to maintain this extensive range, it was apparent that there would be many players with an interest in this plan, including U.S. Fish and Wildlife Service; U.S. Department of Defense; U.S. Environmental Protection Agency; county forests; Sand County Foundation; Georgia-Pacific Corporation; Consolidated Papers, Inc.; Wisconsin Department of Agriculture, Trade and Consumer Protection; utility companies; railroad commissions; Menominee Indian Nation; Winnebago Indian Nation; and Wisconsin Woodland Owners Association.

The proposed plan would emphasize processes that maintain the shifting barrens areas across the landscape such as fire, cutting, and mowing, rather than relying solely on permanent protection of fixed parcels of land. "We want a plan that integrates conservation and economic land use in a manner that is both ecologically and economically sound. And we want to involve landowners and other individuals and groups that have interests in both using and protecting this habitat," explains Cathy Bleser of the Department's Bureau of Endangered Resources. The plan would integrate Karner blue butterfly conservation with existing land uses and would identify ways for landowners to carry out activities on their lands that will avoid or minimize harm to the butterfly and even provide additional areas of barrens for the butterfly to colonize. The plan would take a landscape-scale approach to conservation and would focus restoration efforts on those areas where the best opportunities exist.

The planning process was proposed to the U.S. Fish and Wildlife Service in April 1994, and the Department has initiated discussions with many groups. A goal of July 1997 was agreed upon as the target date for a final plan.

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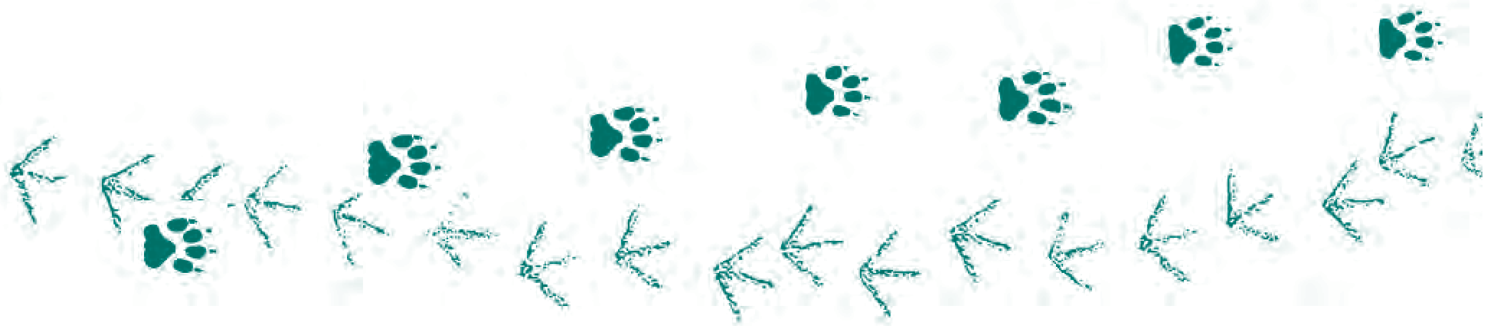

CHAPTER 8

Grassland Communities

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Description

In this document, the term *grassland* refers collectively to several native Wisconsin plant communities. These include prairie, brush prairie (i.e., prairie with oak grubs and shrubs less than six feet tall), sand barrens, bracken-grassland, fen, and sedge meadow (southern and northern) as defined by Curtis (1959). Common characteristics of these communities are (1) lack of trees and tall shrubs and (2) dominance by graminoid (grass and sedge) species.

Wisconsin's grasslands are at the periphery of North America's extensive mid-continental grassland biome which lies south and west of the state. Historically, Wisconsin grasslands were maintained primarily by frequent fires, as was most of the North American grassland biome.

Treelessness is generally the optimum state for maximum development and health of these grassland systems. Although grasses and sedges dominate vegetative biomass in this community type, forbs (non-graminoid wildflowers) dominate the species composition. The most represented families of forbs are the composite (aster), legume, milkweed, carrot, and rose families. Over 400 species of native vascular plants are characteristic of Wisconsin grasslands, and most of these are restricted to grassland or grassland/savanna communities. Detailed descriptions of Wisconsin's grassland plant communities can be found in the classic text by Curtis (1959). Wisconsin grasslands also have a diverse and specialized fauna, especially among the invertebrates, herptiles, and birds.

Prairie (French for "meadow") was the only word early French explorers had to describe the extensive, treeless, and grass-covered landscapes of central North America. *Prairie* subsequently became the term used to describe the grassland type most prevalent in Wisconsin prior to Euro-American settlement. Prairie in Wisconsin was located mostly in the southern and western parts of the state. It occurred across a wide range of topographies, soil types, and soil moisture regimes. This variety of edaphic conditions resulted in a great diversity of prairie flora.

Prairie (French for "meadow") was the only word early French explorers had to describe the extensive, treeless, and grass-covered landscapes of central North America. Prairie subsequently became the term used to describe the grassland type most prevalent in Wisconsin prior to Euro-American settlement.

Fen is a highly restricted type of wet prairie that supports an unusually specialized flora. It forms on wet to moist and often peaty, calcareous soils that have developed over a diffuse groundwater discharge area that is often under artesian pressure.

Sedge meadow is at the extreme wet end of the prairie continuum and was the second most common grassland type in the state. It is distinguished from wet prairie by having (1) more sedge than grass vegetation, (2) more organic than mineral soil, and (3) seasonally standing water. It also supports a less diverse flora than wet prairie.

Bracken-grassland was the northern version of prairie and was found mostly north of the tension zone, which is a band 10-30 miles wide, running from the northwest to southeast corners of the state, separating the two major floristic provinces of Wisconsin (Curtis 1959). It was not abundant historically. Although similar to prairie in structure, bracken-grassland is floristically very different (Curtis 1959:314-21), with bracken fern being a dominant species. This limited vegetation type is covered in the "Oak and Pine Barrens" section.

Sand barrens is also a limited grassland type. It is similar to dry sand prairie, but has far sparser vegetation, and it generally includes exposed sand or sandblows. Most sand barrens today are artifacts of post-Euro-American-settlement activity, primarily failed attempts at agriculture.

> North America's mid-continental grasslands have been in existence for millions of years . . . . Original land survey records of the 1830s indicate there were 3.1 million acres of treeless grassland in Wisconsin, or 9% of the total land cover (Curtis 1959) . . . . Tallgrass prairie and related oak savanna are now the most decimated and threatened plant communities in the Midwest and in the world.

Status

Past

North America's mid-continental grasslands have been in existence for millions of years. Originating in the rain shadow that developed with the uplifting of the Rocky Mountains, they have been expanding and contracting with major climatic changes ever since. They made their most recent incursion into what is now Wisconsin approximately five to six thousand years ago and remained relatively stable here until Euro-American settlement in the mid-1800s. Original land survey records of the 1830s indicate there were 3.1 million acres of treeless grassland in Wisconsin, or 9% of the total land cover (Curtis 1959). A little over two-thirds of this open land (2.1 million acres) was prairie, and approximately one-third (1 million acres) was sedge meadow (see Fig. 10).

Northern sedge meadow in Douglas County. Structurally, sedge meadow is a grassland but hydrologically, it is a wetland. *Photo by Eric Epstein.*

Present

Over the past 150 years, the mid-continental grassland biome has been greatly reduced and degraded throughout its range. Most grassland acreage has suffered one of the following fates: (1) conversion to crop production, (2) overgrazing, or (3) invasion by shrubs and trees due to lack of fire, lack of grazing, or both. With productive soils and ample precipitation, the eastern portion of the grassland biome (including Wisconsin), known as *tallgrass prairie*, was thoroughly fragmented and almost totally converted to agricultural use. Tallgrass prairie and related oak savanna are now the most decimated and threatened plant communities in the Midwest and among the most decimated in the world.

According to the State Natural Heritage Inventory, Wisconsin has only 0.5% (13,000 acres) of its original grassland ecosystem remaining in a relatively intact condition, and much of this remnant acreage has been degraded to some degree by livestock grazing or woody invasion. Over 80% (11,000 acres) of this remaining acreage is sedge meadow, and the rest (2,000 acres) is native prairie. However, the inventory is not nearly as complete for sedge meadow as it is for prairie; there are many acres of secondary and small tract sedge meadows not included in the acreage total.

These remnants represent only 1.1% and 0.1% of the original sedge meadow and prairie acreage, respectively. Most of the surviving prairie is either dry or wet; the intermediate type (mesic prairie), once the most common type in the state, is now virtually gone. Only about 100 acres (0.01%) of an original million acres of mesic prairie are known to exist, and these are in small (often linear), scattered parcels of a few acres at best.

Wisconsin's grassland plants and animals responded to the changes that came with Euro-American settlement in various ways. Some species adapted well and maintain healthy populations today, while some are persisting only in low numbers. Others are restricted to prairie and sedge meadow remnants, and a few have been extirpated.

An estimated 15%-20% of the state's original grassland flora is now considered rare in the state. Seventeen species are currently on Wisconsin's endangered species list; 17 species are on the threatened species list; and 29 species are of special concern in the state (Table 7). This pervasive rarity among grassland plants is due to the extensive loss of the original grassland sod and the conservative nature of many grassland plants, which are rarely found outside of native vegetation remnants. Some, such as prairie gentian and hoary puccoon, are so conservative that

Table 7

Rare and declining Wisconsin grassland plants. Compiled from Wisconsin Department of Natural Resources (1992).

Status	Scientific Name	Common Name
Extinct	(none)	
Extirpated	*Asclepias meadii**	Mead's milkweed
	Platanthera blephariglottis	white-fringed orchid
Endangered	*Agalinis skinneriana***	pale false foxglove
	Anemone caroliniana	Carolina anemone
	Anemone multifida	Hudson Bay anemone
	Astragalus crassicarpus	prairie plum
	Astragalus neglectus	Cooper's milk vetch
	Fimbristylis puberula	chestnut sedge
	*Lespedeza leptostachya**	prairie bush clover
	Liatris punctata	dotted blazing star
	Parnassia parviflora	small-flowered grass-of-parnassus
	Phlox glaberrima	smooth phlox
	*Platanthera leucophaea**	prairie white-fringed orchid
	Polygala incarnata	pink milkwort
	Prenanthes crepidinea	great white lettuce
	Prenanthes aspera	rough white lettuce
	Ruellia humilis	wild petunia
	Scirpus cespitosus	tussock bulrush
	Scutellaria parvula	small skullcap
Threatened	*Agastache nepetoides*	yellow giant hyssop
	Agalinis gattingeri	round-stemmed false foxglove
	Asclepias lanuginosa	wooly milkweed
	Asclepias sullivantia	prairie milkweed
	Cacalia tuberosa	prairie Indian plantain
	*Cirsium hillii***	prairie thistle
	*Cypripedium candidum***	white lady-slipper
	Echinacea pallida	pale purple coneflower
	Eleocharis rostellata	beaked spike-rush
	Hypericum sphaerocarpum	round-fruited St. John's wort
	Lesquerella ludoviciana	bladderpod
	Opuntia fragilis	brittle prickly-pear
	Parnassia palustris	marsh grass-of-parnassus
	Parthenium integrifolium	wild quinine
	Polytaenia nuttallii	prairie parsley
	Platanthera flava	tubercled orchid
	Tofieldia glutinosa	false asphodel

Continued on next page

they are rarely if ever successful in restoration attempts.

The current rarity of many of these species is not limited just to Wisconsin but is also characteristic throughout their range. Three Wisconsin species, Mead's milkweed, prairie bush-clover, and prairie white fringed orchid, are on the federal list of threatened species, and six others, prairie thistle, glade mallow, tubercled orchid, prairie fame-flower, pale false foxglove, and eared false foxglove, are being considered for federal listing.

Most of Wisconsin's grassland vertebrates adapted to the changes in the land. Noted exceptions are the extirpated megafauna (i.e., bison, elk, and wolves), and smaller, specialized animals such as the ornate box turtle and the long-billed curlew. Species that did adapt made use of croplands, pastures, old fields, roadsides, and other highly altered, surrogate "grasslands." However, in the past few decades even these areas have declined in acreage and quality due to changing agricultural practices and land use (e.g., increased use of pesticides, extensive conversion of small grain and pasture acreage to row crops, and changes in the nature and timing of agricultural disturbances, including the early and frequent mowing of alfalfa) and invasion by woody growth into fence lines and open fields.

Some prairie mammals adapted to the initial loss of prairie vegetation and more recent land-use changes and are thus still doing well in Wisconsin today. These include the prairie mole, thirteen-lined ground squirrel, harvest mouse, and prairie deer mouse. Other species have not adapted well to the changes, and have been either extirpated as mentioned above or are now of special concern in the state. The special concern species include Indiana little short-tailed shrew, white-tailed jack rabbit, Franklin's ground squirrel, and prairie vole.

Wisconsin's grassland plants and animals responded to the changes that came with Euro-American settlement in various ways. Some species adapted well and maintain healthy populations today, while some are persisting only in low numbers. Others are restricted to prairie and sedge meadow remnants, and a few have been extirpated. An estimated 15%-20% of the state's original grassland flora is now considered rare in the state.

Grassland bird populations were substantially altered by Euro-American settlement. But because grassland birds are not strictly dependent upon native vegetation, they are one group that generally did not decline solely because of the loss of native vegetation. They are, however, sensitive to both the structure of vegetation (e.g., degree of treelessness, vegetation height and

Status	Scientific Name	Common Name
Special Concern	*Agoseris cuspidata*	prairie dandelion
	Aristida dichotoma	poverty grass
	Artemisia frigida	prairie sagewort
	Callirhoe triangulata	poppy mallow
	Carex richardsonii	Richardson's sedge
	Carex suberecta	prairie straw sedge
	Carex torreyi	Torrey's sedge
	Cassia marilandica	Maryland senna
	Dasistoma macrophylla	mullein foxglove
	Eleocharis robbinsii	Robbin's spike-rush
	Eleocharis wolfii	wolf spike-rush
	Gentianopsis procera	small fringed gentian
	Houstonia caerulea	bluets
	Liatris spicata	marsh blazing star
	Napaea dioica	glade mallow
	Oenothera serrulatus	toothed evening primrose
	Orobanche ludoviciana	Louisiana broomrape
	Orobanche uniflora	one-flowered broomrape
	Panicum wilcoxianum	Wilcox's panic grass
	Penstemon hirsutus	hairy beardtongue
	Penstemon pallidus	pale beardtongue
	Petalostemum villosum	villous prairie clover
	Physalis grandiflora	white ground cherry
	Polygala cruciata	cross milkwort
	Psoralea argophylla	silvery scurfy pea
	Psoralea esculenta	pomme-de-prairie
	Solidago ohioensis	Ohio goldenrod
	*Talinum rugospermum***	prairie fame-flower
	*Tomanthera auriculata***	eared false foxglove

* Federally threatened. ** Concern at federal level.

Table 7 (cont'd)

Rare and declining Wisconsin grassland plants. Compiled from Wisconsin Department of Natural Resources (1992).

density, and amount of residual ground cover) and size of habitats, as well as to the nature and timing of agricultural disturbances mentioned above. Radical changes in these habitat features have been occurring over the past 150 years; often these changes have had direct or indirect ramifications for bird populations. For example, species with large minimum area requirements (area-sensitive species) such as sharp-tailed grouse, greater prairie-chicken, and short-eared owl, are not thriving today, in part because of the fragmentation and reduction of large habitat tracts.

> Little is known about the status of invertebrates in our native grasslands. In fact, there are probably dozens of grassland insects in Wisconsin still unknown to science . . . . Many species may have already been extirpated or become extinct without our having known of their existence.

Today, grassland bird species vary in their status. Of those that were historically present in Wisconsin, a few are still doing very well, often because they (1) are generalists that can use a variety of habitat types (e.g., red-winged blackbird, mourning dove, and song sparrow) or (2) have adapted to intensive row-crop agriculture (e.g., killdeer and horned lark). However, the status of most grassland birds is far less secure than that of these few species. A variety of species adapted well to the low intensity agriculture that occurred before the late 1950s, and they thrived until then. However, in the past 30 years many of them (e.g., bobolink, eastern meadowlark, field sparrow, and grasshopper sparrow) have begun to decline, due in part to the changes in land use and agricultural practices mentioned above. Other species, such as greater prairie-chicken and sharp-tailed grouse, did well after Euro-American settlement, but they did so partly by expanding their ranges into the vast logged and burned-over lands of northern Wisconsin. As the northern habitat grew back to forest, these species eventually declined as well.

As a result of a combination of factors including habitat changes over the past 150 years on breeding grounds, wintering grounds, or both, and habitat-related problems with nest productivity, 16 of Wisconsin's grassland bird species are now of special concern in the state (Table 8); one (greater prairie-chicken) is on the state's list of threatened species. In addition, three other grassland birds, whooping crane, long-billed curlew, and swallow-tailed kite, have been extirpated from the

Table 8

Rare and declining Wisconsin grassland birds.

Status	Common Name
Extinct	(none)
Extirpated	whooping crane* long-billed curlew swallow-tailed kite
Threatened	greater prairie chicken
Special Concern	northern harrier sharp-tailed grouse upland sandpiper short-eared owl dickcissel Henslow's sparrow grasshopper sparrow** Le Conte's sparrow sharp-tailed sparrow lark sparrow bobolink** western meadowlark** yellow rail Wilson's phalarope sedge wren northern pintail
Declining	savannah sparrow** eastern meadowlark** vesper sparrow** field sparrow** blue-winged teal**

* Federally endangered.

** Declining in recent years based on federal breeding bird surveys conducted in Wisconsin.

state due in part to their inability to adapt to land-use changes and unregulated hunting. All three extirpated species now have reduced ranges, but none is extinct. One, the whooping crane, is federally endangered.

Only about one-half of Wisconsin's prairie-associated reptiles and amphibians are still at good population levels today. These include eastern tiger salamander, six-lined racerunner, blue racer, eastern plains garter snake, and Butler's garter snake. Like many other vertebrates, their success has been due to their ability to adapt to surrogate "grasslands." The rest of the prairie reptiles have not adapted as well and are apparently suffering from habitat loss and fragmentation. Of this group, three (ornate box turtle, western slender glass lizard, and massasauga rattlesnake) are on the state list of endangered species, one (Blanding's turtle) is on the state list of threatened species, and two (prairie ringneck snake and bull snake) are on a list of special concern in the state.

Little is known about the status of invertebrates in our native grasslands. In fact, there are probably dozens of grassland insects in Wisconsin still unknown to science. For example, a cursory search for leafhoppers at 14 Wisconsin prairie remnants in 1993 and 1994 revealed five leafhopper species new to science and 24 species never before recorded from the state (K.G.A. Hamilton, Agriculture Canada, Ottawa, pers. comm.). Many species may have already been extirpated or become extinct without our having known of their existence. In light of this ignorance and the fact that there are often close relationships between invertebrates and vegetation (e.g., host plant specificity at the species, genus, and family levels), many grassland invertebrates would be considered rare and endangered at both state and federal levels if distribution and population data were available. For example, some information is available about Lepidoptera (moths and butterflies); consequently, 19 grassland Lepidoptera are now on the state's list of special concern; two species, swamp metalmark and regal fritillary, are on the Wisconsin threatened species list (regal fritillary is also being considered for federal listing); and three species, Powesheik skipper, phlox moth, and silphium borer moth, are on the Wisconsin endangered species list.

Projected

What remains of our native grassland systems has neither long-term nor short-term security. In the absence of additional recognition and management, grassland species and remnant vegetation will continue to be lost due to area reduction, fragmentation, isolation, and degradation (ecosystem simplification). However, if recognition, protection, management, and restoration are actively pursued and fostered at levels greater than they have been in the past, most of the biotic diversity of our original grassland ecosystems can be retained within the state over time. But time is running out fast. With each passing year, options for retention or recovery are lost at an accelerating rate, and the costs and efforts needed to retain grassland biodiversity increase.

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Actions Causing Concern

Threats to the future survival of our native grassland flora, fauna, and vegetation remnants can be summarized in six categories:

- ▲ Continued loss of native remnants (both high-quality sites and those moderately degraded by grazing) due to:
  - ✓ accelerating invasion by woody growth on both wet and dry sites (e.g., red cedar is now invading dry bluff prairie so fast that in 20 years most unmanaged bluff prairie remaining in the Midwest will be completely overgrown, and wetland shrubs and trees are increasingly taking over extensive areas of sedge meadow).
  - ✓ tree planting for "wildlife," "aesthetics," and timber/fiber production. (Planting trees into prairie remnants is a common practice, so as to make economic use of sites people perceive as being "worthless.")
  - ✓ public opposition to tree removal needed to restore or maintain grasslands.
  - ✓ rural home building; this is often focused on nonagricultural lands and, thus, prairie remnants.
  - ✓ conversion of traditional prairie pastures (unplowed but grazed prairie) to crops.
  - ✓ drainage and conversion of sedge meadow and wet prairie to muck farming.
- ▲ Continued loss of surrogate post-settlement "grasslands" used by grassland animals (especially birds), due to intensive agriculture and urban development.
- ▲ General lack of attention to native grassland communities by the public, resource managers, and scientists.
- ▲ Resistance to the use of prescribed fire and lack of understanding by the public and professionals of fire effects (i.e., the consequences of both too much and too little fire).
- ▲ Invasion by aggressive exotics (e.g., honeysuckle, common buckthorn, reed canary grass, leafy spurge, parsnip, purple loosestrife, etc.).
- ▲ Habitat fragmentation, which results in patch isolation and the creation of edge effects. This is especially harmful to vertebrate animals.

[top] Spring Green dry prairie seen in 1975 with the beginnings of red cedar invasion. *Photo by Bill Tans.*

[bottom] The same view of Spring Green dry prairie in 1991 with red cedar nearly covering the hillside. *Photo by Richard Henderson.*

Socio-Economic Issues

Strong public support will play a vital role in retaining and regaining grassland biodiversity in Wisconsin. Management of the grassland ecosystem, or at least elements of it such as open treeless habitat for grassland birds, is compatible with many traditional wildlife management and hunter interests (i.e., species such as ring-necked pheasant, upland nesting ducks, sharp-tailed grouse, and prairie chicken). Livestock grazing and crop production are also potentially compatible with maintaining the open habitat structure needed by many grassland animal species. Agricultural and soil conservation programs, such as the Conservation Reserve Program (CRP), and water quality protection can also be very compatible with grassland habitat interests.

> Strong public support will play a vital role in retaining and regaining grassland biodiversity in Wisconsin.

There is already some public awareness and interest in both prairie flora (as exemplified by the popularity of prairie restoration and landscaping) and grassland birds that are well known and popular with bird watchers, such as sandhill crane, prairie chicken, meadowlark, bobolink, Henslow's sparrow, and upland sandpiper. These combined interests should translate into public support for grassland habitat preservation and restoration. There is already much support among private conservation groups for prairie and sedge meadow protection and recovery; for example, mesic prairie is a top preservation priority for The Nature Conservancy; there is a new and growing regional conservation group called The Prairie Enthusiasts; and The Madison Audubon Society is supporting a large prairie restoration on land they hold.

Potential for Community Restoration

Recovering and maintaining native grassland biodiversity in Wisconsin is very feasible for many but not all components (e.g., birds, plants, and invertebrates) of the system. It is unlikely that we will ever again be able to accommodate mega-fauna such as bison, elk, and wolves in a naturally functioning grassland ecosystem in Wisconsin.

Retention of grassland biodiversity will require more than just the preservation of existing high-quality remnants of native vegetation. Most remnants are less than ten acres in size and very few exceed 50 acres. They are just too small for many if not most vertebrate animal species. Small sites, however, are capable of supporting viable populations of most plant species, most soil microflora and microfauna, and many other invertebrate species for decades if not centuries to come, especially if the sites contain soil moisture gradients and are provided with buffer land.

Remnants degraded by grazing or woody growth invasion can also play a significant role. Degraded areas are much more common and often larger than high-quality remnants. Their value is in the residual species they still harbor and the great potential they have for recovery. Their condition is often such that recovery can be accomplished solely by brush removal, restrained grazing, or fire. The greatest opportunities for recovery of degraded sites are at the dry and wet ends of the soil moisture spectrum, where several thousand acres of degraded dry prairie and sedge meadow still exist.

Recovery of the mesic prairie system is a different situation. Because mesic prairie remnants of any quality are very rare, retaining or regaining components of this system will require extensive buffering of the few remaining remnants and much

> Restoration will not be easy, and it will take much time, maybe even centuries, before the prairie community is significantly restored. However, restoration is feasible. Many elements of the system can still be found in forgotten corners of the landscape, and they can be brought back together with reasonable effort.

Mesic prairie remnant between hay and corn fields. Most mesic prairie has been converted to agriculture. The soil on which mesic prairies occurred is deep and fertile. Ipswich Prairie, Grant County. *Photo by Eric Epstein.*

restoration from scratch (i.e., on sites highly altered by tillage or other intense disturbance). Such restoration will not be easy, and it will take much time, maybe even centuries, before the prairie community is significantly restored. However, restoration is feasible. Many elements of the system can still be found in forgotten corners of the landscape and they can be brought back together (i.e., translocation of individuals or reintroduction by seed) with reasonable effort. As reduced and fragmented as the prairie ecosystem is in Wisconsin, local genetic variations of species, particularly plants and invertebrates, still survive in low numbers on the landscape. This genetic diversity can still be accessed for restoration. Although restorations should be viewed as long-term, they can, in as little as a decade, result in reasonable facsimiles of prairie that support far more biotic diversity than alternative grass covers such as brome or switchgrass.

Given the fragmented nature and small size of native remnants and even potential restorations, the main hope for grassland vertebrates lies with surrogate "grassland" habitat that does not necessarily have native vegetation. The opportunities for establishing this habitat are extensive on both private and public lands, especially DNR-managed lands. In many cases establishment would only require removal and control of woody growth. In others it would require the establishment of permanent grass/forb cover.

Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

Efforts at recovery and maintenance of grassland biodiversity in Wisconsin should focus on three general areas of concern: (1) bird, herptile, and small mammal communities that require large habitat areas but not necessarily native vegetation; (2) native community remnants (vegetation, soil, and invertebrates); (3) endangered or threatened animal species that have requirements for both native vegetation and large areas (e.g., ornate box turtle). Species in the latter category will need specific recovery plans, which are not addressed here. Possible actions that address the first two concerns are as follows:

1. Establish treeless grassland habitat at several landscape scales to meet area requirements for species ranging from the prairie chicken to the grasshopper sparrow. Examples of both lowland and upland habitats should be sought, and most projects should be in former native grassland areas. Rationale for the latter requirement is that historical grassland areas will have the soil, topography, remnant vegetation, lack of large trees, and climatic conditions most conducive to restoring and maintaining open grassland habitat. However, some regions of existing cleared forest or drained marsh may prove suitable as well.

   The total acreage of permanent grass/forb cover needed for maintaining viable populations of grassland birds in the state is unknown. At least 3%-4% (90,000-125,000 acres) of the original acreage may be required. However, even more important than total acreage is the placement and configuration of these acres. The following three-part strategy is recommended:

Large Landscapes. Establish 4-5 landscape regions of at least 10,000 acres each that are as treeless and open in character as possible. Within each region there should be a core area of permanent grass cover that is at least 2,000 acres in size. Within the rest of the region there should be at least 35% permanent cover, 75% of which should be in units of 40 acres or more. The remainder (52% of total) can stay in crop production. Small grain and hay crops should be encouraged.

Small Landscapes. Establish 10-12 landscape regions of 1,000-5,000 acres each, with permanent cover cores of at least 250 acres and a 15% permanent cover over the rest of the region. Follow the same guidelines used in the large landscape regions.

Scattered Tracts. Establish numerous scattered grass/forb fields that are at least 20 acres in size when there are no edge effects from trees or other obstructions. If edged by trees, the minimum acreage should be 40 acres. Total acreage goals should be approximately 50,000 acres. When possible these fields should be placed in close proximity to other permanent grass/forb cover.

In the development of these "grassland" habitat areas, a variety of grass/forb cover types should be used. Incorporation of native remnants and restoration of native vegetation should be encouraged, but not made an absolute requirement. For more detailed habitat recommendations, see Sample and Mossman (1990). In addition, a Bureau of Research Technical Bulletin on grassland bird status and management is presently being written.

2. Manage, enhance, and restore native vegetation remnants as refugia for flora, invertebrates, and ecological processes. For the most part these efforts will be at scales far smaller than those used for the "grassland" habitat discussed above. However, some acreage overlap of the two programs is likely to occur and should be encouraged. Recommended strategies for maintaining and recovering the two major grassland types of the state—sedge meadow and prairie—are as follows:

   Sedge Meadow. The total acreage needed to ensure the long-term survival of the sedge meadow plant and invertebrate communities in the state is unknown. One to two percent (10,000-20,000 acres) of the original one million acres may be a reasonable target.

   Highest priority should be given to the protection, maintenance, and recovery of the largest and most intact examples. However, small, high-quality sites (as small as ten acres) should not be overlooked; such areas may represent the last refuge for many sedge meadow plant, insect, and soil microflora and microfauna species. Special priority should also be given to sedge meadows that are part of larger grasslands or wetland complexes.

   Once the high-quality sites are secure (including adequate buffer lands), degraded areas with high recovery potential should be considered for completing the acreage goals. Restoration of sedge meadow from scratch is not a desirable recovery strategy at this time, because of the adequate amount of remnant acreage that still exists and the great difficulties associated with sedge meadow restoration.

Curtis Prairie, UW Arboretum, an example of dry mesic prairie. Restorations such as this will be needed to meet the possible acreage goals for native grasslands restoration. *Photo by Richard Henderson.*

Buffer lands will be crucial to the long-term (100 years or more) survival of all prairie remnants, especially the smallest ones, and their dependent species.

Prairie. As with sedge meadow, the total acreage needed for long-term survival of the prairie plant and invertebrate communities in the state is unknown. Again, 1%-2% (21,000-42,000 acres) of the original 2.1 million acres may be a reasonable target. In the case of prairie, however, this goal is at least ten times greater than the total known acreage of all high- to moderate-quality prairie remnants combined, and it probably exceeds the combined acreage of all remnants, including degraded ones (i.e., remnants not included in the inventory). Therefore, some restoration from scratch will be needed to meet the acreage goal, preferably on buffer lands surrounding remnants.

Highest priority should be put on the protection and maintenance of all high-quality remnants of an acre or more in size, followed by degraded remnants of five acres or more. High-quality sites as small as 1-2 acres should not be ignored, especially when they contain mesic prairie, for they are probably the last refugia for many prairie plant, insect, and soil micro-organism species. In addition, because of the near total loss of prairie, these small remnants now collectively function as the repository for the genetic diversity of most prairie plants and invertebrates.

These repositories must not be lost. Their genetic holdings will be needed in any future prairie restorations.

Buffer lands will be crucial to the long-term (100 years or more) survival of all prairie remnants—especially the smallest ones—and their dependent species. Buffer lands are needed to protect remnants against the negative impacts of external influences and stochastic events, and to provide living space into which the prairie community can spread and rebuild marginal populations. Ideally, buffer lands should also provide those portions of the soil-moisture spectrum not found in the remnant. In most cases this will be mesic soil. It would also be ideal to buffer remnants by including them in larger grassland bird habitat areas.

3. If we are serious about long-term retention of grassland biodiversity in Wisconsin, eventually we will need three or four large-scale restorations (greater than 1,000 acres) that encompass clusters of existing remnants. Such acreage is needed for natural landscape processes to occur. Having such areas will also eventually reduce management costs per acre; for the effort required to maintain a remnant community is inversely proportional to the size of the remnant.
4. The current DNR/DOT Native Plant Seed Program, which will be supplying local genotypes, must be encouraged and expanded if restoration on a large scale is to become feasible.
5. Whatever the final acreage goal for either surrogate "grassland" habitat or native remnant vegetation, it should include representation of a variety of soil and topographic types, as well as geographic locations. Based on historical occurrence, the total acreage goal should be shared among DNR Districts in the following approximate proportions:

Southern District 45%
Western District 32%
Northwest District 12%
North Central District 5%
Southeast District 5%
Lake Michigan District 1%

To reach these goals, some acquisition of private land will be needed, especially for remnant sites. However, much of Wisconsin's native grassland biodiversity can be maintained and regained without new land acquisition. Many opportunities exist for maintenance and recovery on land already managed by the DNR, especially in the programs of the Bureau of Parks and Recreation and the Bureau of Wildlife Management. Much could also be accomplished outside of DNR lands through cooperation and partnerships with other agencies (e.g., roadside programs) and private conservation groups. There are also many opportunities for encouraging surrogate habitat and remnant management on private lands through tax incentives (e.g., the Minnesota Prairie Bank Program), educational programs, agricultural programs (i.e., agricultural policy, farm bills, continuation of CRP and annual set-aside), technical advice and assistance, and the Habitat Restoration Areas component of the Wisconsin Stewardship Program.

6. Because of the current rarity and long-time absence of prairie on the landscape, a program of education/awareness is greatly needed for developing support for prairie recovery and maintenance. The Department's Bureau of Parks and Recreation and the Bureau of Information and Education should play major roles in this.

7. Develop a policy on prescribed burning that recognizes the dependence of some ecosystems, including grasslands, on fire and examines the resources and staff support necessary to effectively and safely use fire to manage these fire-dependent communities. In addition, air quality standards and policies within the Department's Division of Environmental Quality will need to be clarified.

A policy for prescribed burning that recognizes the dependance of some ecosystems, including grasslands, on fire need to be developed. *Photo by Richard Henderson.*

8. Qualitative inventories of selected invertebrate taxa in remnants of prairie and sedge meadow and other grassland types (including non-native surrogates) are needed for the purpose of determining what specialized, remnant-restricted species still exist, their distribution, and their status. This information, which is currently lacking for the most part, would be of great assistance in setting protection and management priorities.

9. Much additional research is needed on the effects of grassland management techniques, such as burning, mowing, and grazing, on grassland vegetation and fauna. Obtaining this information will be crucial to our long-term ability to manage grasslands for the entire array of native grassland biodiversity.

10. Planning and coordination among all land management interests, especially within the DNR, is crucial, so that programs do not inadvertently cancel each others' efforts. For example, tree planting programs should strive to avoid destruction of prairie remnants or fragmentation of grassland habitat and, conversely, grassland habitat projects should avoid areas that are more appropriate for reforestation. Integrated management is the key to overcoming these types of management and policy conflicts.

Case Study

The Glacial Habitat Restoration Area: An Approach for Restoration of Grassland Communities

Contributed by Becky Isenring and Richard Henderson.

Native grasslands are among the most threatened natural community types in the state. Thus the Department faces a tremendous challenge in addressing the needs for restoration of these communities and preserving the native species in them. One approach that takes a step towards this end is the Glacial Habitat Restoration Area (HRA).

The primary objective of the Glacial HRA is to provide nesting habitat on a landscape scale for upland nesting waterfowl, native grassland non-game birds, and pheasants. This is to be achieved by restoring 10% of the land within a selected region of the state to a suitable condition. Restoration will be accomplished through a program of acquiring land rights through fee title and perpetual easements and then restoring the land to grassland and wetland habitat.

Innovations of the Glacial HRA project are its size and scope. The area covers 530,000 acres within the glaciated, former prairie/savanna area of southeast Wisconsin. Restoration goals are 38,000 acres of upland grassland habitat and 11,000 acres of wetland habitat distributed in small, scattered units (10-250 acres) within high priority sub-units of the entire HRA project area. The idea is to take an area of the state of manageable size and, applying research-based species management guidelines, reintroduce complexity into a simplified landscape. The priority sub-units were identified using Geographic Information System (GIS) analysis of three landscape habitat models developed for prairie waterfowl, native upland grassland birds, and pheasants. Any area that met the minimum criteria for at least two of the three habitat models became high priority for the programs restoration activities.

The Glacial HRA focuses on distributing most of the restoration into small scattered units (smaller than 100 acres). The largest unit goal is 250 acres, of which 12 are being sought within the total HRA. Restoration activities include planting native prairie species mix of 6-20 species.

The Glacial HRA program will do an excellent job of providing the scattered tract component of habitat for upland and wetland grassland birds. It will also meet some needs for native prairie restoration and protection of native sedge meadows.

In the process of implementing the Glacial HRA, Department managers are realizing that it can be used as a springboard into a program that does even more for grassland biodiversity needs. Some ideas being considered in statewide discussions include (1) making some management units larger (250-2,000 acres) because the program could go farther to meet the habitat needs of grassland birds, mammals, and reptiles if the restoration units were larger; (2) using seed from local sources and planting it in mixes of 80 plus species to increase benefits to include a broader range of wildlife species; (3) making native prairie remnants acquisition priorities so that the Glacial HRA would help to meet the total protection and restoration needs of native prairie vegetation, its associated soil communities, and prairie-restricted macro-invertebrates; and finally (4) having Department managers discuss how they can take what they have learned from the Glacial HRA and apply it to other areas of the state that have native prairie and sedge meadow restoration opportunities.

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CHAPTER 9

Wetland Communities

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Wetland communities vary widely in their plant and animal composition. For example, northern bogs, such as this muskeg and bog along the Black River in Douglas County, are generally acidic and support species adapted to very different conditions than the alkaline marshes of southern Wisconsin. *Photo by Eric Epstein.*

Description

All *wetlands* have a common characteristic—soils or a substrate that is periodically saturated with or covered by water. The statutory definition of a wetland used in Section 23.32 (1), Wisconsin Statutes is "an area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions."

People often think of wetlands as cattail marshes utilized by waterfowl and muskrats. However, many other types of wetlands occur in Wisconsin and are given names such as wet meadow, swamp, bog, fen, sedge meadow, shrub-carr, alder thicket, conifer swamp, and bottomland or lowland hardwood forest. Curtis (1959) described wetland communities for Wisconsin and discussed their general characteristics and relative diversity of plant species (Table 9). Wetlands vary in their plant and animal composition and in their diversity. Northern bogs, for example, are generally acidic and support fewer plant and animal species in fewer numbers than the alkaline marshes of southern Wisconsin.

Detailed wetland classification systems have been developed. The earliest, most widely used major classification system for wetlands in the United States was developed by Shaw and Fredine (1956). However, this system was overly simplistic and was replaced with the U.S. Fish and Wildlife Service's *Classification of Wetlands and Deep-Water Habitats of the United States* (Cowardin et. al. 1979). Wisconsin's classification system (Wis. Dep. Nat. Resour. 1992*c*) is based on this system, but incorporates some modifications to make it easier to use and understand. (See Payne 1992 for comparison of wetlands classification systems.)

Wetlands are part of the water cycle of all ecosystems, and their location in the landscape allows them to function as a buffer between upland areas and surface waters (Weller 1981). Wetlands perform a number of natural functions that benefit natural ecosystems and society. Water quality is often dependent upon wetlands because they serve to trap sediment, remove nutrients, protect shorelines, and slow the effects of flood water. They also serve as both discharge and recharge areas for groundwater and provide habitat for

Table 9. Wetland Communities of Wisconsin (from Curtis 1959)

Community	Description	Approximate Original Area
Southern Lowland Forests	Found along river valleys and on lake plains primarily south of theTension Zone; also in depressions on poorly drained moraine; known as bottomland or floodplain forests along rivers and hardwood swamps on lake plains; floodplain forests present along all of the major rivers in southern Wisconsin; hardwood swamps found around the larger existing lakes and also on extinct glacial lakes. American elm was formerly important in all southern lowland forest types.	420,000 in the two types.
Southern Wet Forests	Dominated by boxelder, black willow, cottonwood, silver maple and river birch.	Very small, probably only 20% of total bottomland forest or 84,000 acres.
Southern Wet-Mesic Forests	Dominated by silver maple, green ash, swamp white oak, and hackberry.	Uncertain. Probably 80% of total bottomland or 336,000 acres.
Northern Lowland Forests	Include tamarack-black spruce bog forests, white cedar-balsam fir conifer swamps, and the black ash-yellow birch-hemlock swamps; found on lake beds and along streams north of the Tension Zone.	2,240,000 in the two types.
Northern Wet Forest	Dominated by black spruce and tamarack; white cedar, balsam fir, and jack pine of secondary importance; with an understory of mosses, sedges, and ericaceous shrubs; occurs on acid peat.	Uncertain. Possibly 75% of total northern lowland forest or 1,680,000 acres.
Northern Wet-Mesic Forest	Cedar swamps are dominated by white cedar and balsam fir; with hemlock, yellow birch, and black ash of secondary importance. Hardwood swamps are dominated by black ash with yellow birch birch, red maple, and white cedar.	Uncertain. Possibly 25% of total northern lowland forest or 560,000 acres.
Open Bog	Has a continuous carpet of sphagnum moss; found in pitted outwash or kettle depressions, mostly in northern Wisconsin with a few relicts in southern Wisconsin; dominant families are the Ericaceae and Cyperaceae; bog shrubs include rosemary, leatherleaf, bog laurel, and Labrador tea.	No information. Probably less than 5% of conifer swamps or 110,000 acres.
Alder Thicket	Common along springy areas with mineral or muck soils, along streams, and around lakes north of the Tension Zone; dominated by tag alder.	Unknown.
Shrub-Carr	Common around lakes and ponds and invades sedge meadow south of the Tension Zone; wet-ground community dominated by tall shrubs other than tag alder; dominated by red osier dogwood and willow species.	Unknown.
Sedge Meadow	Open community of wet soils where more than half the dominance is contributed by sedges rather than grasses; found in all regions of the state in extinct lake beds, around the shores and banks of lakes and streams, and in depressions in pitted outwash or moraine topography.	1,115,000 acres in the two types.
Northern	Tussock meadows (dominated by *Carex stricta*) occur statewide and are generally smaller in the north. Wire-leaved sedge meadows are found mostly in northern Wisconsin and can cover thousands of acres.	Uncertain. Probably 105 or 115,00 acres.
Southern	Dominated by *Carex stricta* and bluejoint grass; occur along streams and lakeshores and in morainal lowlands.	Uncertain. Possibly 90% or 1,000,000 acres.
Calcareous Fen	Shrub-herb community on a wet and springy site with an internal flow of alkaline water; found more frequently in southeastern counties.	Very small, probably only a few hundred acres.
Wet Prairie	Grassland on wet soils; located south of the Tension Zone; dominated by bluejoint grass, sloughgrass, big bluestem, and prairie muhly grass.	Uncertain. Possibly 5% of total prairie or 105,000 acres.
Wet-Mesic Prairie	Grassland on seasonally wet soils; located south of the Tension Zone; dominated by big bluestem, bluejoint grass, sloughgrass, and wild rye.	Uncertain. Possibly 20% of total prairie or 420,000 acres.
Emergent Aquatic Communities	Group of wetland communities along the dividing line between true aquatic and true terrestrial communities. Includes deep and shallow marshes. Found along streams and streamside marshes throughout Wisconsin and along lakes in glaciated Wisconsin.	Unknown.

Wetlands are part of the water cycle, and their location in the landscape allows them to function as a buffer between upland areas and surface waters. This ecosystem, which includes pond, ridge, fen, open bog, and upland along Lake Superior, serves as a natural buffer that traps sediments, removes nutrients, and protects the shoreline. *Photo by Cliff Germain.*

many species of plants and animals (Stearns 1978).

Wetlands are interrelated and interspersed among all the other community types described in this report. Many wetlands are forested (e.g., wet forests and wet mesic forests) and must be considered as part of the continuum of northern or southern forest ecosystems. Wetlands are also interspersed among the prairie and oak savanna areas of southern and east-central Wisconsin. The spatial connections between wetlands, lakes, rivers, and streams are obvious to anyone who has spent time in wetland communities.

Unique to wetland communities and aquatic communities are the state and federal laws that govern their use. These are the only community types in Wisconsin for which a body of law regulating use has developed. As discussed later, these laws developed over many decades as these communities suffered continued destruction. The direct positive effects wetlands exert on water and water quality served as the driving force behind the development of these regulations. In contrast, no regulations to protect terrestrial communities from permanent loss and alteration have been developed.

Unique to wetland communities and aquatic communities are the state and federal laws that govern their use. These are the only community types in Wisconsin for which a body of law regulating use has developed.

Status

Past

Wisconsin's topography was shaped largely by glacial activity. As a result, wetland communities were abundant in Wisconsin before Euro-American settlement and occupied an estimated ten million of the state's 35 million acres (see Table 9). This estimate is based on the original government land surveys of the early 1800s and modern soil surveys; it may be a low estimate, since the data used by surveyors in the 1800s were based on a wetland definition that is conservative compared to our current definitions and because few soils have been mapped in northwestern Wisconsin (Wis. Dep. Nat. Resour. 1990).

In the Driftless Area of the state, which was not affected by the most recent glaciation, forested and nonforested wetlands existed primarily along streams and rivers or as spring seeps. In other regions of the state, wetlands occurred on vast areas of peat soils occupying former glacial lake beds, as potholes and fens; along streams and rivers; on the borders of lakes; as bogs, forested swamps, and bottomlands; and as estuaries and coastal wetlands along Lake Michigan and Lake Superior.

Wetlands have been subjected to intense modification and use and have greatly decreased in number since Euro-American settlement. Nearly all remaining wetlands have suffered from the effects of simplification and fragmentation. From the beginning of Euro-American settlement in the early 1800s until relatively recently, wetlands were viewed as wastelands and were given economic value only when drained or filled (McCormick 1978). The 1850 Federal Swamp Land Act officially set national policy as one of wholesale wetland "reclamation." In Wisconsin, wetland loss was also accelerated by the 1925 Wisconsin Drainage Law (Kabat 1972).

Historically, the greatest threat to wetlands in Wisconsin has been from agricultural drainage and urban development. Nationally, more than 87% of wetland losses have been due to agricultural development (Tiner 1984). Since wetlands often occur along rivers and lakes, these sites have also been considered to be of particular value for port facilities, for industrial development that required access to water for transport, for industrial processing or cooling water, for the discharge of wastes, for marinas, for residential developments with access to water, and for deposition of dredge materials during construction of channels and wharf facilities (McCormick 1978).

Many thousands of acres of wetlands were eliminated by shoreline development for homes, resorts, and commercial and industrial development. As many of Wisconsin's larger cities expanded, forested wetlands and the marshy estuaries of rivers were cleared and filled to accommodate development. For example, most of the industrial areas in Milwaukee, Superior, and Green Bay are built on fill deposited in coastal wetlands. Portage, La Crosse, and Prairie du Chien are Wisconsin cities built partly on riverine wetlands (Visser 1982).

Historically, some appreciation for unaltered wetlands began to appear in the 1930s, although drainage and filling continued to be promoted by federal and state policies. During that period, concern for wetlands was prompted in part by the catastrophic decline in North American waterfowl populations during the droughts of the 1930s (Kabat 1972). Nevertheless, an era of intensified agriculture began following World War II, which included heavy applications of fertilizers and pesticides, increasingly mechanized agriculture, and continued wetland clearing and draining, subsidized by federal programs and tax incentives. However, beginning in the late 1940s, with continued momentum into the 1970s, wetlands achieved ever-wider recognition as valuable natural resources. Increasingly, land-use plans recommended various levels of wetland preservation; acquisition of wetlands for both state and national waterfowl management steadily increased; and new research began to show the relationship between wetlands, water quality, economically important fish and wildlife species, and the preservation of rare plant and animal species (Kabat 1972, McCormick 1978, Visser 1982).

> Wetland communities were abundant in Wisconsin before Euro-American settlement and occupied an estimated ten million of the state's 35 million acres . . . . Wetlands have been subjected to intense modification and use and have greatly decreased in number since . . . settlement.

Gradually, as the ecological values of wetlands were recognized, changes began to occur in federal and state policies towards wetlands. The former view that wetlands were just wastelands and impediments to progress was replaced by a recognition that wetlands are critical components of healthy functioning ecosystems with significant direct and indirect economic benefits.

The oldest of federal laws used to protect wetlands is the River and Harbor Act of 1899, which prohibited the excavation or deposition of material into any navigable water of the United States without a permit from the U.S. Army Corp of Engineers. Although this act had the

Wetlands are interrelated and interspersed among all other community types. Many wetlands are forested and are part of the continuum of northern and southern forest ecosystems, as shown here by the concentric bands of open bog, forested bog, and forested upland in Washburn County. Wetlands are also interspersed among the prairie and oak savanna areas of the state. *Photo by Robin Moran.*

The former view that wetlands were just wastelands and impediments to progress was replaced by a recognition that wetlands are critical components of healthy functioning ecosystems with significant direct and indirect economic benefits.

potential for major wetland protection, it was administered in a manner that greatly limited its effectiveness (McCormick 1978). The National Environmental Policy Act of 1969 required that many wetland drainage and filling projects be reviewed for their impact on the human environment, particularly if federal agencies or federal money was involved. The Federal Water Pollution Control Act of 1972 required permits for the disposal of dredge material and the filling of waters of the state, including wetlands. The Federal Endangered Species Act of 1973 called attention to the need to protect and restore wetland habitats for endangered plant and animal species.

The 1985 and 1990 Federal Farm Bills contained milestone provisions for protecting wetlands by imposing penalties for converting wetlands to agricultural uses, thus ending the federal agricultural subsidy for wetland drainage. These restrictions, which are known as the "Swampbuster" provisions, helped to stem the rate of wetland conversion to agricultural uses. The 1990 Farm Bill also contained a wetland reserve program which allows the U.S. Department of Agriculture to take permanent wetland easements on restored wetlands on private lands.

Paralleling wetland protection actions on the federal level during this time period, a number of legislative actions occurred in Wisconsin to strengthen state authority to protect wetlands. Prior to the 1960s, the state's role consisted of buying wildlife habitat, fish spawning grounds, and public hunting areas. The state also had authority under Chapter 30 of the Wisconsin Statutes Navigable Water Law to control filling on the beds of navigable waters (Visser 1982).

Established in 1966, Section 144.025 of the Wisconsin Statutes required the Department to protect the waters of the state, including wetlands. In the same year, Section 59.971 of the Wisconsin Statutes required counties to adopt shoreland zoning ordinances for unincorporated areas within 1,000 feet of lakes and flowages and within 300 feet of navigable streams. Rules for implementing s.59.971 were promulgated in NR 115 Wisconsin Administrative Code. (Further references to the Wisconsin Administrative Code will be shortened to "NR.") In 1979, the Wisconsin Legislature approved a statewide wetland inventory program, but the program had no concurrent protection authority. In 1980, the Natural Resources Board adopted NR 1.95, which required Department personnel to consider the effect on wetlands when granting permits and to minimize wetland damage in the permitting process. Also in 1979, NR 115 was amended to require counties to protect wetlands within 1,000 feet of lakes and within 300 feet of streams. An analogous rule, NR 117, was approved to protect wetlands occurring within cities and villages. NR 115 and 117 prohibit wetland alteration without first obtaining a rezoning approval from the county, city, or village. The Department can veto a rezoning approval if the local government fails to consider significant environmental factors in granting the rezoning (Dawson 1982, Visser 1982).

The most recent wetland protection law in Wisconsin is NR 103, which establishes state water quality standards for wetlands. These narrative standards are applied to all Department activities that affect wetlands. They are also applied to federal permits through the state's water-quality certification process under the Clean Water Act.

During the era of the most intensive wetland loss and modification, wildlife and other natural resource values associated with wetlands were recognized only in passing. As a result, along with the loss of wetland acreage, there was a concomitant loss in the numbers of species dependent on wetlands, including waterfowl, shorebirds, herptiles, fish, invertebrates, and many species of plants. There was also a loss of the ecosystem services performed by wetlands, including floodwater storage, sediment and contaminant filtering, and groundwater discharge and recharge.

The species richness of many wetland types prior to Euro-American settlement does not appear to be well-documented. There are, however, indications from historical observers that many marshes attracted large numbers of migrating waterfowl, were important for fish spawning, and produced large amounts of useful products such as lumber, sphagnum moss, wild rice, and marsh hay (Curtis 1959).

Present

At present, Wisconsin has lost 47% of its original ten million acres of wetlands. Many of the remaining 5.3 million acres are in the northern third of the state (Wis. Dep. Nat. Resour. 1990). In some southern Wisconsin counties, the amount of wetland loss is well over 75%. Wisconsin's losses are reflective of the national status of wetlands; it is estimated that one-half of the nation's original 221 million acres of wetlands have been lost (Feierabend 1992). A large amount of remaining acreage in Wisconsin exists in a partly altered state, such as with old drainage ditches still functional enough to change the hydrology of the wetland. Much of this remaining wetland acreage was at one time disturbed, either by drainage (followed by restoration) or by being cleared, repeatedly burned, grazed, or periodically plowed (Curtis 1959).

Wisconsin has lost 47% of its original ten million acres of wetlands.

Although there is considerably less drainage of wetlands today due to the "Swampbuster" requirements of the 1985 Farm Bill, agriculture still affects wetlands through grazing, barnyard and feedlot runoff, pesticide and fertilizer runoff, and sedimentation from nonpoint sources. Sedimentation of wetlands leads to the gradual loss of open-water areas and development of monotypic stands of vegetation that have less habitat value to wildlife.

Currently, the collective use of Section 404 of the Clean Water Act, the "Swampbuster" provisions, NR 115, NR 117, and NR 103 have controlled major wetland losses in Wisconsin (Dale Simon, Wis. Dep. Nat. Resour., pers. comm.). The Department plays the lead role in preventing wetland loss through an aggressive regulatory program involving local, federal, and state governments. In addition, there are a number of incentive programs, many rather recent in origin, that are designed to restore or enhance wetlands.

Many wetlands have been lost to agricultural drainage, urban development, and industrial development. Channelization of streams, like this one in the central sands region, was used to drain land and resulted in a simplified and less diverse stream system. *Photo by Michael J. Mossman.*

One newer program involves the U.S. Department of Agriculture Farmers Home Administration (FmHA). As part of the 1985 Farm Bill, FmHA was given the authority to place restrictive-use wetland easements on properties they offer for sale after foreclosure. These wetland easements are then enforced by the U.S. Fish and Wildlife Service. FmHA can also allow borrowers to reduce their debt by granting an easement to the Fish and Wildlife Service. Under the 1990 Farm Bill, the U.S. Department of Agriculture was authorized to take permanent wetland easements. However, Congress funded the program in 1992 only, so its effects have been very limited. Additional wetland protection opportunities occur in other federal laws such as the Coastal Zone Management Act of 1972 and the Fish and Wildlife Coordination Act.

Overall, these state and federal regulatory programs have the capability to substantially reduce wetland losses in Wisconsin. However, contained in these regulations are some exemptions for agriculture, forestry, and various types of commercial navigation activities. These exemptions have been criticized by ecologists and wetland protection advocates as being unnecessary, and efforts continue to bring all activities affecting wetlands under regulatory review.

In addition to protecting wetlands through regulations, the Department and the U.S. Fish and Wildlife Service have a commendable record of acquiring wetlands for wildlife and fishery management, natural areas, and other purposes in the state. Between the U.S. Fish and Wildlife Service, the Department, and nonprofit conservation organizations, hundreds of thousands of acres of wetlands have been acquired, and many thousands of acres of drained wetlands have been restored. Notable large wetland acquisition and restoration projects are Horicon Marsh National Wildlife Refuge, the Glacial Lake Grantsburg Wildlife Area Complex, Necedah National Wildlife Refuge, Mead Wildlife Area, Meadow Valley Wildlife Area, Green Bay West Shores Wildlife Area, the Upper Mississippi National Wildlife Refuge, and the Mink River Estuary. Additionally, many thousands of acres of small wetlands and associated uplands have been purchased. Much of this acquisition was focused on waterfowl and fishery management, but significant benefits are provided to other wetland-dependent species such as sandhill cranes and other wading birds, furbearers, herptiles, and plants. A number of private organizations have also protected large areas of wetlands.

Many thousands of acres of small wetlands and associated uplands are in state and federal ownership. Much of this acquisition was focused on waterfowl and fishery management, but significant benefits are provided to other wetland-dependent species such as sandhill cranes and other wading birds, furbearers, herptiles, and plants.

Wetland management practices conducted to improve waterfowl habitat have impacted wetlands in the state. The principles and techniques used and their implications are discussed by Weller (1978, 1981) and Payne (1992). In most cases, these activities have restored large areas of wetlands that had been drained for agriculture. Many of the drained wetlands were originally sedge meadows, shrub-carr, tamarack swamps, and wet prairie; however, shallow lakes were also drained. Restorations for waterfowl habitat often resulted in shallow and deep-water marshes that may not have been the condition of the wetland before it was drained. Some habitat improvement projects also purposefully converted sedge meadows, shrub-carr, and wet prairie into shallow and deep-water marshes under the justification that these wetlands were being enhanced for waterfowl and wildlife. The result has been that wildlife and plant species needing shallow and deep-water marshes have greatly benefited, while species that preferred the pre-existing wetland type suffered some habitat reduction. From a statewide perspective, however, the areas of wetland affected by wildlife management activities are a small portion of the total wetland modification or loss that occurred due to agriculture and urban development. The net effect of wildlife management wetland restoration and enhancement projects on biodiversity appears to be positive. Current wildlife management of wetlands focuses on restoring many of the original shallow and deep-water marshes that were drained for agriculture.

On both national and state levels, renewed emphasis was placed on the value of wetlands for waterfowl and other aquatic wildlife with the implementation of the North American Waterfowl Management Plan beginning in 1986 (U.S. Fish and Wildl. Serv. 1986). This program, signed by Canada and the United States, encourages public-private partnerships in protecting and restoring wetland habitats. The plan is continental in scope, recognizing that many species of birds associated with wetlands need secure habitats across the entire North American continent. Wisconsin is a direct participant in this effort through the Upper Mississippi River and Great Lakes Region Joint Venture (Wis. Dep. Nat. Resour. 1992*a*)

The Wisconsin Wetland Inventory (Visser 1982, Wis. Dep. Nat. Resour. 1992*c*), authorized by the Legislature in 1979, was initially completed for all counties in 1984. Wetlands two acres or larger in size are delineated and classified on 1:24,000-scale maps. These inventory maps were supposed to be updated every ten years, but limited funding has slowed the process to a 20-year cycle (Dale Simon, Wis. Dep. Nat. Resour., pers. comm.).

Wetlands are noted for their abundance of plant and animal life. Of Wisconsin's 370 species of birds, 39% live in or use wetlands. According to Hale (1982), no other Wisconsin habitat type comes close to this avian occupancy rate. Hale also commented that although no wetland bird species has been extirpated from Wisconsin due to wetland destruction, the significant loss of wetland acreage has to have caused a decline in wetland-dependent birds.

> 43% of all federally listed threatened and endangered species use wetlands at some point in their life cycle. 32% of the state's threatened and endangered plants and animals are wetland-dependent.

Many important game birds, mammals, and fish are associated with wetlands. Waterfowl, beaver, muskrats, and northern pike are obvious examples. However, other species are also significantly related to wetlands. In some river systems, such as the Wolf River, walleye use seasonally flooded wetlands for spawning. Ring-necked pheasants use shrub-carr and cattail marshes during the winter. White-tailed deer thrive in wetland areas composed of shrubs and trees.

Vogt (1981) identified southern lowland forests as "exceptionally rich" and aquatic communities (including open-water marshes) as "extremely rich" in herptiles, as compared with other community types in Wisconsin. Since many herptiles are

Wetlands provide habitat for many species. This forested bog in Douglas County supports breeding pairs of at least sixteen species of warblers. *Photo from Department of Natural Resources files.*

associated with wetlands, these species have suffered from the loss of wetlands.

Currently, 43% of all federally listed threatened and endangered species use wetlands at some point in their life cycle (Feierabend 1992); for Wisconsin, 32% of the state's threatened and endangered plants

The prairie white-fringed orchid (*Platanthera leucophaea*), a showy state endangered and federally threatened species, occurs in wetlands in the southern part of Wisconsin. *Photo by Thomas A. Meyer.*

The hardwood swamp has recently been identified as a discrete community in Wisconsin. The ash swamp, including the Ashland County site pictured here, is very wet and is dominated by black ash and alder with mineral rich groundwater. *Photo by Eric Epstein.*

and animals are wetland dependent (Charles Pils, Wis. Dep. Nat. Resour., pers. comm.). Tables 10 and 11 show the wetland species currently on Wisconsin's endangered and threatened species lists.

Considering the vast acreage of northern and southern wetlands that have been drained, cleared, intensively grazed, repeatedly burned, plowed, flooded to create recreational lakes, or filled, it is possible to appreciate how local populations of species became disjunct from one another and eventually extirpated because they could not adapt to the changes in plant succession or were unable to withstand the changes in their microclimates. Migratory species and more mobile species probably suffered less than those with limited or no mobility. The preservation of wetland species that are essentially immobile is dependent upon land protection programs such as state, federal, and private acquisition or cooperative programs with private landowners. Currently, Wisconsin has an aggressive program of identifying and protecting lands with high natural-area value using the Natural Heritage Inventory. The highest ranking examples of all wetland types are considered priorities for permanent protection in the Department's Natural Areas program.

Projected

The enforcement of existing wetland-use regulations should prevent further major loss of wetlands in Wisconsin. It is not possible for every remaining acre of wetland to be preserved. In our society, some wetland loss will be unavoidable, but rigorous planning and analysis of alternatives should help to minimize losses and avoid negative impacts from the perspective of concern for biodiversity. A major threat would result if the federal government changed its definition of wetlands, thus eliminating protection under Section 404 of the Clean Water Act for millions of acres of wetlands (Wis. Dep. Nat. Resour. 1992*b*). This definition is a major issue in the upcoming reauthorization of the Clean Water Act in 1995.

Table 10

Endangered and threatened wetland animal species.

Herptiles		Birds		Lepidopterans	
Endangered	**Threatened**	**Endangered**	**Threatened**	**Endangered**	**Threatened**
Blanchard's cricket frog	Blanding's turtle	yellow-throated warbler	red-shouldered hawk	Powesheik skipper butterfly	swamp metalmark butterfly
massausauga rattlesnake	wood turtle	trumpeter swan	cerulean warbler	silphium borer moth	
western ribbon snake		Caspian tern	hooded warbler		
northern ribbon snake		Forster's tern	yellow-crowned heron		
queen snake		common tern	great egret		
			red-necked grebe		

Existing state, federal, and private wetland acquisition and easement programs will continue for the foreseeable future. There are also plans covering the Mississippi River (U.S. Army Corps Eng. 1991) and the Lake Winnebago Pool Lakes (Wis. Dep. Nat. Resour. 1989) to enhance wetland areas that have been severely degraded. The recent surge of effort to restore wetlands on private lands enrolled in the Conservation Reserve Program will continue as long as the program continues. This work could be considerably enhanced if the U.S. Congress and Department of Agriculture would commit to long-term funding of the Wetland Reserve Program; to date, Congress provided funding for 1992 only.

Watershed-based, nonpoint pollution control programs will continue to expand. These activities will afford major opportunities to work with private landowners to achieve water quality benefits and wetland preservation and restoration goals. In many watersheds, restoring wetlands will be a major technique for achieving nonpoint pollution objectives.

A continuing driving force behind wetland acquisition, management, and protection in Wisconsin will be the desire to enhance hunting and fishing opportunities. Organizations such as Ducks Unlimited, Wisconsin Waterfowl Association, Trout Unlimited, The Nature Conservancy, the Wisconsin Wildlife Federation, the Conservation Congress, and others will continue to be very active in assuring that state policies protect wetlands. These groups now are also working with other conservation groups to integrate their specific interests with broader goals for water quality, nongame wildlife, soil erosion control, and aesthetics, all of which contribute to the protection of biodiversity.

If all of these programs and efforts are continued, wetland acreage in Wisconsin could increase somewhat; at least many wetland areas not being farmed or otherwise drained will be restored. These efforts will also result in better protection of undisturbed wetlands and improved management. The cumulative result should be a better assurance that the biodiversity of wetlands statewide will be protected and enhanced wherever possible. Since wetlands are so interspersed among the other major community types in the state, the biodiversity benefits of protecting, restoring, and enhancing wetlands will contrib-

> Since wetlands are so interspersed among the other major community types in the state, the benefits of protecting, restoring, and enhancing wetlands will contribute to the ecological health of these communities, also.

Table 11

Endangered and threatened wetland plant species.

Endangered	Threatened
auricled twayblade	beaked spike rush
angle-stemmed spikerush	false asphodel
prairie white-fringed orchid	English sundew
netted nut-rush	lenticular sedge
floating marsh marigold	coast sedge
hop-like sedge	Michaux's sedge
chestnut sedge	bald rush
bog rush	calypso orchid
pink milkwort	round-fruited St. John's wort
tussock bulrush	bog bluegrass
lake cress	white lady's slipper
alpine milk vetch	marsh valerian
crow-spur sedge	linear leaved sundew
brook grass	marsh grass-of-parnassus
hemlock-parsley	ramshead lady-slipper orchid
beak grass	small round-leaved orchid
chestnut sedge	Garber's sedge
umbrella sedge	sweet coltsfoot
Fassett's locoweed	algal-leaved pondweed
heart-leaved plantain	sheathed pondweed
seaside crowfoot	
small yellow water crowfoot	

ute to the ecological health of these communities, also.

Actions Causing Concern

Although the era of large-scale, federally subsidized wetland drainage and filling has been assumed to be over, changes in federal policy could dramatically alter the current condition. Nationally, wetlands are afforded major protection due to the provisions of sections 404 and 401 of the Clean Water Act and the 1985 and 1990 Farm Bills. These provisions were recently under serious threat by attempts to redefine what a wetland is in the federal manual for identifying and delineating wetlands (Wis. Dep. Nat. Resour. 1992*b*). The proposed changes would have more narrowly defined wetlands, and the impact would be highly significant. In Wisconsin, for instance, under the proposed *1991 Wetland Delineation Manual*, as much as 80% of the state's wetlands would not fall under the new definition and thus not be afforded the protection they now have (Dale Simon, Wis. Dep. Nat. Resour., pers. comm.).

In coming years, wetland-filling will continue to be an increasing threat to wetland areas, as pressures for nonagricultural land use become more intense. Shoreline development on inland lakes is continuing but is subject to county regulation. Since most of the best lakeshore properties have already been developed, those that remain are less desirable; sometimes these are wetland areas that the owner wants to fill for development. The loss of these wetlands would have negative implications for water quality and wetland species habitat. Application of existing regulations will be required to prevent negative impacts.

Highway construction also continues to affect wetlands. Wetlands often cannot be avoided during highway corridor selection due to concerns for human safety, farm operations, industry, and historical use patterns. Thus competing public purposes—i.e., wetlands protection and highway safety—lead to compromises to mitigate wetland losses. While the goal is to achieve no-net-loss of wetlands, it is very difficult to replace all the functions and values of wetlands that are lost to highway development, particularly in the immediate area of the loss.

Harvesting of forest products can affect forested wetlands, mainly through changes in the microclimate when overstory trees are removed and soil is compacted by equipment.

Wetlands will continue to be affected by agriculture through grazing, barnyard and feedlot runoff, pesticide and fertilizer runoff, sedimentation from nonpoint sources, and drainage. Landowners not participating in federal commodity support programs may still drain wetlands. Cranberry operations have the potential to affect wetlands by converting existing wetlands to cranberry beds, through the application of pesticides and through the development of water storage reservoirs.

Agriculture in the United States and the world is undergoing major change. Free trade agreements, the changes in Eastern Europe, the demise of the Soviet Union, and the national deficit all affect U.S. agricultural trends. If remaining wetlands are to be preserved, it will be necessary to incorporate their protection into sustainable-agricultural policies that recognize the need to be sensitive to ecological values while producing the food, fiber, and other products needed by society. In the U.S., the Clean Water Act and the Farm Bill are due for reauthorization in 1995. Wetland-agricultural issues will be major considerations in both acts.

The invasion of wetlands by exotic plant and animal species is a significant problem. For example, reed canary grass has been an extremely aggressive invader of sedge meadows. It has significantly displaced native species on many thousands of acres of sedge meadows and shrub carr in the southern parts of the state. When this plant dominates a site, other species are excluded and the community becomes highly simplified. Controlling reed canary grass is very difficult and expensive.

Similarly, purple loosestrife is rapidly invading many wetlands throughout the state. It is an exotic species, first released in this country by nurseries and gardeners, and it crowds out native species. Control of this plant is very difficult, labor-intensive, costly, and controversial, since herbicides may be necessary (Payne 1992). Research has been conducted on importing weevil species from their original habitats in Europe as a biological control; results show promise. So far a dozen states have released weevils for loosestrife control. Wisconsin did its first release in 1994.

Common carp, another exotic species imported from Europe, has had serious negative effects on many wetlands associated with lakes and rivers. During feeding, carp root out aquatic plants, causing turbidity that prevents the regrowth of plants and greatly reducing aquatic invertebrate diversity and abundance. Wetlands with high carp populations have noticeably less abundant wildlife populations than similar types of wetlands without carp. Control is difficult; the best that may occur would be periodic population reductions using intensive harvesting or chemical treatment (Payne 1992). The aquatic plant and wildlife response following a major reduction in carp populations in a wetland is very dramatic.

The lack of fire in some wetland communities results in gradual invasion of woody shrubs and trees, eventually leading to a change in the wetland type. This is most significant for sedge meadows, fens, and shrub-carrs (Curtis 1959). As sedge meadows and other seasonally flooded wetlands convert to dense shrub and forested wetlands, the wildlife species needing open, herbaceous habitat are replaced by those preferring forest and dense shrubs. In Wisconsin prior to Euro-American settlement, this condition was dynamic. During drought periods, wetlands often burned—which set back succession—and often "peated in," creating shallow open-water depressions. Many wetlands that have had their hydrology permanently disrupted by drainage systems are now generally drier than they were originally, which favors shrub and tree growth over herbaceous vegetation. Restoring fire as a natural process in wetland communities can be highly beneficial (Payne 1992).

Beaver can have major effects on wetlands. From a positive standpoint they can help maintain water levels and set back succession into herbaceous wetlands. On the negative side, their dam building activity can severely affect communities such as fens and bogs when associated plant and animal life is replaced by persistent high water levels. In recent years high beaver populations in many parts of Wisconsin have undoubtedly had a wide variety of effects on wetland communities. The long-range effect of elevated beaver populations on wetland community biodiversity is unknown even though local effects may appear quite severe.

Many wetlands are dependent upon seasonal flooding. Elimination of this water

This Wisconsin River floodplain forest is dominated by silver maple. Many wetland communities, including this southern wet-mesic forest, are dependent upon seasonal flooding. Elimination of this water recharge can change the character of a wetland over time. *Photo by William Tans.*

recharge can drastically change the character of a wetland over time. Drought cycles can be beneficial to wetlands through enhanced recycling of nutrients (Sloey et al. 1978), but prolonged drought can result in substantial vegetational changes. For example, cattail and shrub invasion during dry periods can be so dense as to exclude wetland species that require a major open-water component (van der Valk and Davis 1978, Weller 1981). During drought periods many wetlands can also be farmed, resulting in disturbance from cropping or grazing. During the period prior to Euro-American settlement, buffalo and, perhaps, herds of elk had significant impacts on wetland vegetation in some parts of the state. Grazing and trampling probably helped maintain a herbaceous cover. However, this use was seasonal and temporary, unlike the continuous grazing and trampling by domestic livestock that occurs today in some wetlands. Thus controlled, periodic grazing can be used to maintain some types of wetlands (Payne 1992).

Socio-Economic Issues

The role of wetlands as essential components in the healthy functioning of ecosystems has gained broad recognition in the last 20 years. Because so much wetland acreage has already been lost, many regulatory programs have been developed to protect remaining wetlands for the myriad of values they provide to society. While their value for wildlife and plant life has been most promoted, there is ever-growing awareness among ecologists and land-use planners that protecting wetlands for their flood storage, sediment and nutrient filtering, and groundwater recharge/discharge capabilities provides services to our human communities that cannot be simply duplicated with engineered facilities (Stearns 1978, Weller 1981). Thus, in the future there will be more land-use planning that avoids impacting existing wetlands and more proposals that call for the restoration of wetlands where possible. It appears we may be at the beginning of an era of major wetland restoration because of the growing public recognition of wetland values to society and the economy.

Despite this trend towards greater protection, wetlands will continue to be affected by agriculture, highway construction, commercial navigation, and urban/suburban development. In our society, it is probably not realistic to assume every remaining acre of wetland can or should be preserved. However, enough is now known about wetlands, their values, and their functions that any proposed permanent loss must be very carefully considered.

Wetlands are also important for recreation, aesthetics, and education. They provide open spaces in landscapes that are becoming increasingly rare as development continues. Hunters and anglers use them for recreational pursuits. They can be used seasonally for canoeing, hiking, and cross-country skiing. Viewing and listening to wildlife are also popular wetland activities. The bird life in wetlands is often particularly easy to observe, making wetlands favorite bird-watching and photography areas.

Potential for Community Restoration

In assessing the potential for and possible effects of restoring wetlands, the specific characteristics of the types of wetlands and the types of disturbance involved must be considered. Most permanently lost wetlands are those that have been filled or excavated. Some disturbed wetland communities will readily respond to protection, restoration, and management techniques but others may need many decades to return to a pre-altered state. Because wetland communities differ, some thrive with periodic disturbance while others need long-term stability. Wetlands drained for agriculture often quickly respond to restoration efforts, since seed banks can lie dormant for many years (even decades) waiting for the right conditions to flourish (Weller 1981). Many wildlife species will re-inhabit wetlands within a few years, some within days or months. Once drainage has been stopped, the hydrological functions of a wetland may return somewhat to pre-drained conditions. The ability for drained and partially drained wetlands to be restored to an ecologically functional level allows decisions to be made regarding how much wetland acreage should be restored and where. Since much wetland loss has been due to agriculture, it is highly feasible to design wetland restoration programs that fully integrate with water-quality and sustainable-agriculture programs.

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Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

1. Federal legislation and programs encouraging wetland protection and restoration need to be supported. U.S. Department of Agriculture policies linking participation in commodity support programs to wetland protection need to be continued and enforced. For example, the Conservation Reserve Program and the Wetland Reserve Program will need to be reauthorized in the 1995 Farm Bill. The Clean Water Act Sections 401 and 404 are also due for reauthorization in 1995. Attempts to define wetlands politically rather than scientifically should be opposed.

2. The effectiveness of existing federal, state, and local regulatory programs needs to be continually evaluated. The protection of existing wetlands and the restoration of wetlands depends upon the combined efforts and support of many levels of government interacting with agricultural, business, industrial, and other interests. Good communication and the creation of shared goals and values is essential to prevent attempts at weakening regulations to serve special interests.

3. State, federal, and local land acquisition of wetlands needs to occur in an ecoregion context. Wetland complexes, rather than individual wetlands, have been and should continue to be the focus of acquisition. Wetland acquisition programs should be integrated with prairie and oak savanna acquisition programs, as these communities were originally highly interspersed with wetlands and have been the most severely reduced in acreage. Current public wetland acquisition efforts by the Department, the U.S. Fish and Wildlife Service, or other public agencies should be continued. The Natural Heritage Inventory is capable of identifying high-quality undisturbed wetlands which should be given protection from disturbance.

> Despite this trend towards greater protection, wetlands will continue to be affected by agriculture, highway construction, commercial navigation, and urban/suburban development.

4. Better integration should occur among the goals and objectives of the many interests in wetland restoration and management involving Department programs such as Wildlife, Fisheries, Water Resources Management, Forestry, Environmental Analysis and Review, Water Regulations and Zoning, and Endangered Resources; federal agencies;

city and county governments; and the many private organizations contributing money and time, such as Ducks Unlimited, Wisconsin Waterfowl Association, and The Nature Conservancy. Ideally, wetland acquisition, protection, management, and restoration plans would be developed in partnership for each ecoregion of the state. A wetlands management plan has already been developed for Wisconsin as part of the North American Waterfowl Plan Joint Venture. This plan focuses primarily on waterfowl, but it is an excellent document with which to begin integrating other wetland protection needs.

5. Continued education and information programs are needed to develop increased public support and understanding of wetland protection and management activities. Wetland values, functions, and protection and management needs should be emphasized in primary and secondary environmental education curriculums. Public-attitude surveys should be conducted to assess knowledge of, use of, and interest in wetlands.

6. The current 20-year cycle for updating Department wetland inventory maps is inadequate for effective monitoring for state wetland protection and regulatory needs. A ten-year update cycle is desirable but will require additional staff and funding. The inventory mapping program should continue to be integrated with the Department's overall Geographic Information System program and the Department's proposed Aquatic and Terrestrial Inventory.

7. Wetland restoration, development, and enhancement projects should consider the full range of biodiversity concerns. Wetland restoration projects need to assess the biological aspects of restoring a wetland to its pre-altered state versus raising the water level above that which occurred before the wetland was altered. This analysis should take into account the type of wetland that will result from restoration alternatives, including the use of local genotypes, and resulting benefits to a wide variety of wildlife and plant life in a local area and region.

8. Riverine-floodplain wetlands along large rivers in the state should receive additional attention. These lowland and bottomland hardwood forest areas have diminished significantly in the state, and the remaining acreage of these types should receive additional protection. Studies should be conducted to assess the feasibility of restoring these lowland forest wetland types.

9. Coastal wetlands along Lake Michigan and Lake Superior have been severely reduced in acreage. The remaining wetlands should be protected from development through regulation or, if necessary, through easement or fee title acquisition.

10. The issue of mitigation will have to be addressed. Currently, the Department has authority to mitigate only for Department of Transportation highway projects. Pressures to apply mitigation for other types of development will likely increase. The Department must assess the scientific and public policy implications of mitigation to prevent the misuse of this concept, which can contribute to the decline of biodiversity of wetland communities.

11. Additional research should be conducted to understand the long-term effects of using wetlands for stormwater and wastewater disposal. Additional research is also needed to better understand how nutrients, heavy metals, and pesticides are cycled in wetland systems. There is also a need to continue to improve the Department's knowledge base on how to best achieve wetland restoration and management objectives for a wide variety of plant and animal species and communities.

Case Study

Restoring a Prairie Wetland Landscape in Southern Wisconsin

Contributed by Alan Crossley.

Land for Patrick Marsh Wildlife Area was transferred to the DNR by the Department of Transportation (DOT) in December 1991, creating the first wetland mitigation bank site in Wisconsin. The land was purchased by DOT to allow the restoration of a large wetland area known variously as "Patrick Lake," "Brazee Lake," "Brazee Swamp," "Duscheck's Marsh," "Phantom Lake," "The Old Lake," and more recently "Lake Sun Prairie." The goal of the project is to recreate a microcosm of what Patrick Marsh and the surrounding landscape looked like when William Patrick first came upon it in 1841—a large, thriving wetland community surrounded on the uplands by oak openings and tallgrass prairie.

The wetland restoration itself is different from most in that rarely do restorationists have a benchmark from which to evaluate the success or failure of the restoration, especially wetland restorations. Most of the time a wetland restoration merely attempts to restore the hydrology of a site, with no clear picture of what the wetland being restored looked like prior to drainage. Fortunately, we have lots of information about this site.

From the original land survey notes of Orson Lyon in 1834 to the reconstruction of the history of the marsh (beginning in 1841) by Effa Duscheck as part of her address to the Twentieth Century Club of Sun Prairie in 1925, much is known about the marsh. Because of its importance to Sun Prairie life, pictures dating back to the late 1800s show it in various stages of inundation and drawdown. Aerial photographs beginning in 1937 again give a picture of the changing character of this dynamic wetland. And Dr. Robert A. McCabe's study of the nesting ecology of water-obligate birds using the marsh from 1947 to 1951 describes bird use of the marsh and in particular notes the presence of the largest nesting colony of yellow-headed blackbirds in southern Wisconsin. His study also gives a glimpse into the species composition of the aquatic plant community.

The marsh was drained in 1965 after a court battle in which the DNR tried, unsuccessfully, to stop the drainage. But the recent expansion of State Trunk Highway 151 from two lanes to four lanes from Sun Prairie to Columbus set the stage for the cooperative restoration of the marsh as part of a wetland mitigation agreement between DOT and DNR.

Soon after DOT removed the pumping system in the winter of 1991-1992, the marsh began to fill with water. By April of 1992 there were close to 100 acres of water on the marsh with an average depth of about 18 inches and a maximum depth of about three feet. More than 5,000 ducks and 200 tundra swans were observed on the marsh during spring migration. Surveys that year found 13 species of breeding birds using the marsh itself and an additional 26 species using in the uplands. Twenty-eight different species of aquatic plants were already found in the marsh, just six months after it began to fill with water. A survey of frogs and toads found only the American toad present in the marsh.

Continued on next page

This 1937 air photo shows Patrick Marsh as it was—a shallow marsh and wet meadow that supported a wide diversity of plants and animals, including the largest breeding population of yellow-headed blackbirds in southern Wisconsin. *Photo from Agricultural Stabilization and Conservation Service.*

In 1991, when this photo was taken, the marsh was being drained and crops were being grown in it. The outline of the marsh, though, is still clear. *Photo from Agricultural Stabilization and Conservation Service.*

By the spring of 1993, the marsh filled to its normal level of about 160 acres of water with an average depth of almost five feet and a maximum depth of nearly eight feet. Sixteen species of breeding birds were found using the marsh and about the same number in the uplands. Aquatic plant diversity appeared to decrease slightly, perhaps as a result of the deepening water levels. But instead of hearing only the American toad, biologists heard six additional species of frogs. A graduate student working in the marsh found dozens of coot nests, as well as those of pied-billed grebe, sora rail, redhead, mallard, and blue-wing teal, to name a few. Several yellow-headed blackbirds returned to the marsh in 1993, although none were known to have nested.

In 1994, water levels in the marsh stabilized at their maximum level. Bird nest density seemed to be reduced, although nest success seemed to increase. At least two pairs of yellow-headed blackbirds probably nested on the marsh. Tiger salamanders were also caught at the marsh for the first time.

On the uplands, some progress has been made in restoring a few acres of prairie using locally collected native seed, thanks to funding support from DOT, lots of work by DNR wildlife managers, and great volunteer support from local citizens and Madison Audubon Society. During the winter of 1993-1994, many of the weedy tree species in the small wooded areas of the property were removed in favor of oaks and the native shrub understory.

Every day, one can see a car or two parked outside the gates as people walk along the road or stop to watch birds. A Sun Prairie middle school teacher has been working with DNR wildlife managers to use the marsh as an outdoor classroom. During spring and fall, small groups of students come out to the marsh for an hour or two at a time to learn about the wetland, its unique history, and the plants and animals that live in it. A Wisconsin Environmental Education Board grant is also being used to develop an education program at the marsh for Sun Prairie elementary, middle school, and high school classes.

[Top] The pumping system was removed in the winter of 1991–1992, and the marsh began to fill with water. By April 1992, when this photo was taken, there were almost 100 acres of water. More than 5,000 ducks and 200 tundra swans were observed during that spring's migration. *Photo from DNR files.*

[Bottom] By June 1993, when this photo was taken, the marsh was filled to its normal level of about 160 acres. Sixteen species of breeding birds were found using the same marsh, and about that same number were in the uplands. *Photo from DNR files.*

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CHAPTER 10

Aquatic Communities

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Description

Wisconsin has a large and diverse aquatic resource which supports numerous species, communities, ecological processes, and human uses. In addition, many terrestrial species and processes are dependent on neighboring aquatic systems. On a landscape scale, aquatic systems are one integral piece of a larger continuum that includes upland terrestrial systems and transitional wetland areas. The location of a species or community along this continuum is critical to understanding its role in the landscape ecosystem.

Wisconsin waters have been classified based on geographic locations. Frey (1963) identified four major geographic regions: driftless area, northwestern lakes district, northeastern lakes district, and southeastern lakes district. A classification based on nationally identifiable ecoregions was proposed by Omernik and Gallant (1988). Most of Wisconsin lies in four of these ecoregions: northern lakes and forests (NOLF), north-central hardwood forest (NCHF), driftless area (DRFT), and southeastern Wisconsin till plain (SETP) (Fig. 17). Lyons (1989*a*) demonstrated that Wisconsin stream fish communities show a general correspondence with these ecoregions. Other ecoregion classifications have been developed (e.g., Bailey 1989*a*, 1989*b*) and will be used by the Department to develop a classification system for the state.

Most classifications agree that the driftless area is the dominant Wisconsin geologic aquatic boundary. Covering an area missed during the last glaciation, the driftless area is distinguished by classic dendritic stream patterns, few natural lakes, and sharper, more eroded terrain (Becker 1983). In contrast, the remainder of the state was smoothed by glaciation and has less topographic relief. Rivers are sinuous and have less average elevation drop. Glaciers also left substantial numbers of natural lakes. Lakes in northern Wisconsin tend to be cooler, more oligotrophic, and less productive than southern Wisconsin lakes. North-central Wisconsin also has one of the highest concentrations of spring-fed lakes and streams in the world.

Understanding the issues affecting aquatic biological diversity in Wisconsin must involve some generalization of aquatic ecosystem types. A general physical classification includes drainage lakes—impounded or natural lakes whose main water source is from stream drainage and have at least one inlet and one outlet; seepage lakes—landlocked natural lakes whose main water source is the groundwater table and with no inlet or permanent outlet; spring lakes—natural lakes for which the main water source is the groundwater table (springs) but always have an outlet of substantial flow; streams—smaller, low-order flowing waters which form the headwaters of river systems and which usually have a high-moderate gradient; and rivers—larger flowing waters formed by the confluence of several streams and that usually have a low gradient. The lake classifications are derived from the Wisconsin Department of Natural Resources Surface Water Resources program (e.g., Carlson and Andrews 1977).

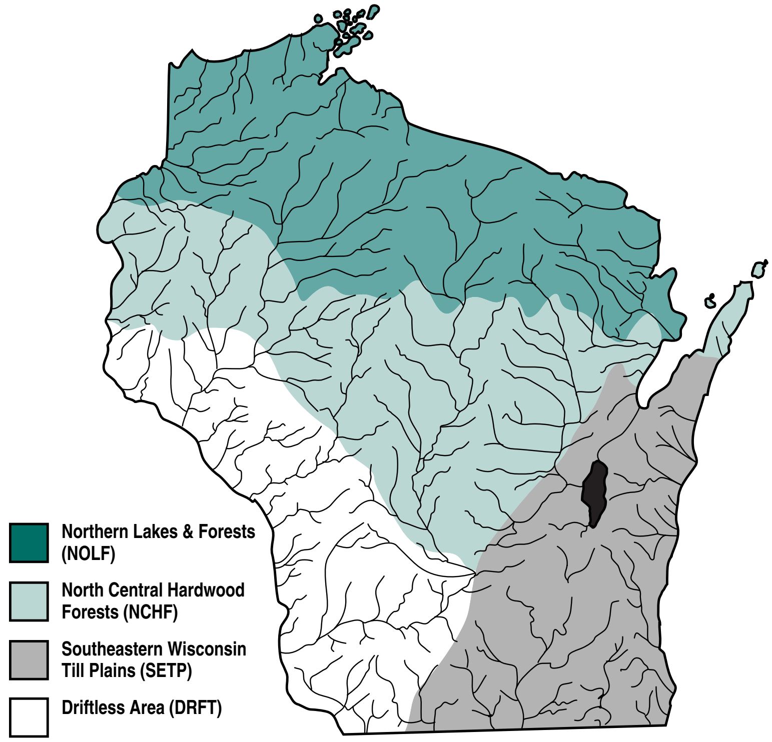

Figure 17

Ecoregions of Wisconsin as developed by Omernik and Gallant (1988). This system is used in this chapter and is one example of how ecoregions could be defined for Wisconsin.

Lakes

Lake communities often vary dramatically based on limnological characteristics. Lakes are often classified according to trophic status. Lakes with very low nutrient input and abundant dissolved oxygen levels throughout the water column are termed "oligotrophic." Oligotrophic lakes, like Lake Superior, are often considered to be the epitome of desirable water quality conditions but have low overall productivity, few species, and relatively simple ecological systems. Conversely, lakes with high nutrient input or high rates of nutrient recycling are termed "eutrophic." Eutrophic lakes that thermally stratify may become devoid of oxygen below the summer thermocline, precluding the production of many species. Eutrophic lakes have high overall productivity and typically support high species diversities and more complex ecological systems. Intermediate lakes with moderate nutrient levels and occasional oxygen depletion are sometimes termed "mesotrophic." Wisconsin also has a special class of lakes termed "dystrophic" or bog lakes, which are primarily affected by natural acidity despite having typical ranges of nutrient input. These dystrophic lakes contain unique communities that have very low species diversity and are among the simplest of ecological systems.

Wisconsin has a large and diverse aquatic resource which supports numerous species, biological communities, ecological processes, and human uses.

Lakes normally undergo a natural succession from oligotrophic to eutrophic although the time span may be thousands of years. Human intervention can shorten this process to a few decades. Lakes receiving unnaturally high nutrient inputs—termed "hyper-eutrophic"—have degraded habitat that results in simplified communities, altered species compositions, and dysfunctional ecological processes.

On a landscape scale, aquatic systems are one integral piece of a larger continuum that includes upland terrestrial systems and transitional wetland areas.

Great Lakes

Wisconsin waters include 1.7 million acres of Lake Superior (Wis. Dep. Nat. Resour. 1988) and 4.7 million acres of Lake Michigan (Wis. Dep. Nat. Resour. 1986) including most of Green Bay. Wisconsin has 156 miles of shoreline along Lake Superior and 407 miles of coastline along Lake

With 6.4 million acres of surface water and 563 miles of shoreline, Wisconsin's Great Lakes represent an immense resource. Geologic features, such as this exposed dolomite along the Lake Michigan shore in Door County, add structural and functional diversity. *Photo by Robert H. Read.*

Michigan (Napoli 1975). Features of national significance include the cobble beach found along only the shoreline of the Door County peninsula; Lake Superior drowned bay mouth estuaries (e.g., St. Louis River, Kakagon Sloughs, and Port Wing) found only along Wisconsin's shore; Lake Michigan drowned bay estuaries (e.g., Marinette, Peshtigo, Green Bay's Atkinson's Marsh) are found primarily along Wisconsin's shoreline; the Apostle Islands National Seashore located in Lake Superior near Ashland; and Lake Superior itself—the second largest freshwater lake in the world.

Understanding the issues affecting aquatic biological diversity in Wisconsin must involve some generalization of aquatic ecosystem types. A general physical classification includes drainage lakes, seepage lakes, spring lakes, streams, and rivers.

Most of Wisconsin's inland lakes are located in northern Wisconsin. Some, such as this lake in Vilas County, are remote and largely undisturbed. *Photo by Michael Mossman.*

The fish communities of Wisconsin's Great Lakes are characteristic of north temperate oligotrophic and mesotrophic lakes.[4] Cold-water communities with lake trout, rainbow trout, brown trout, and coho and chinook salmon as the top predators dominate, but warm-water communities featuring walleye, smallmouth bass, and northern pike exist in littoral and estuarine areas. Cold-water communities contain panfish and non-game species such as deepwater sculpins, bloater, cisco, lake, round whitefish, ninespine stickleback, longnose suckers, rainbow smelt, alewives, and sea lamprey. Warm-water communities contain yellow perch, burbot, white suckers, lake sturgeon, emerald shiners, and carp. Both communities contain a mix of native and introduced species (Downs 1984, 1986). Wisconsin waters of the Great Lakes at one time supported a complex of seven different cisco species, four of which were endemic to the Great Lakes (Becker 1983, Robins et al. 1991).

The macroinvertebrate fauna of Lakes Michigan and Superior is dominated by amphipods (especially *Pontoporeia*), oligochaetes, nematodes, sphaeriids, and chironomids (Cook and Johnson 1974, Dermott 1978, Nalepa 1989). Over 90 taxa of Chironomidae have been collected from southeastern Lake Michigan alone (Winnell and White 1985). A few types of typically lotic water forms such as heptageniids and hydropsychids are common in near shore areas (Barton and Hynes 1978) as well as being present in deeper water (Selgeby 1974). During the mid-1980s the European cladoceran *Bythotrephes cederstroemi* (BC) became established in Lake Huron and quickly spread to the other four Great

[4] Fish and herptile species, for which data are plentiful, are well described in this discussion; other taxa are mentioned throughout the chapter wherever information was made available by contributors.

Lakes (Garton and Berg 1990). Its impact on native zooplankton communities is unknown. It appears inevitable that BC will eventually spread to inland lakes in the Great Lakes region.

Inland Lakes

Wisconsin has more than 14,000 inland lakes covering a million-plus acres (Table 12). Most lakes are located in the northern part of the state. Using the Omernik and Gallant (1988) system of ecoregions, the NOLF ecoregion contains 9,300 lakes covering 455,000 acres, but 85% are glacial or bog lakes of less than ten acres. The NCHF ecoregion contains another 3,200 lakes covering 223,000 acres. In contrast, the DRFT ecoregion, because of its steep topography, contains very few lakes—only 557 covering 68,000 acres. The SETP ecoregion contains only 6% of Wisconsin's lakes but the region includes Lake Winnebago, at 137,708 acres, the state's largest inland lake. The largest concentration of glacier kettle lakes in the world occurs in the Vilas and Oneida county area (Tonn and Magnuson 1982), and a high concentration of spring ponds occurs in the Forest, Langlade and Oneida county area (Carline and Brynildson 1977).

Wisconsin has more than 14,000 inland lakes covering more than a million acres. The largest concentration of glacier kettle lakes in the world occurs in the Vilas and Oneida counties, and a high concentration of spring ponds occurs in the Forest, Langlade and Oneida counties.

Most of these lakes are naturally occurring and of glacial origin. However there are 1,550 dams on state waterways which affect water levels on 666,000 acres (65%) of Wisconsin's inland lakes. A series of hydropower reservoirs on the Wisconsin River system dominate central Wisconsin. The largest reservoirs are Petenwell Flowage (23,040 acres), Castle Rock Flowage (13,955 acres), Big Eau Pleine Reservoir (6,830 acres), Lake DuBay (6,700 acres), and Lake Wisconsin (9,000 acres). Large hydropower reservoirs have also been constructed on the Chippewa-Flambeau river system including Lake Wissota (6,300 acres), Lake Chippewa (15,300 acres), and the Turtle-Flambeau Flowage (13,545 acres). The Mississippi River in Wisconsin has a series of navigation dams which have made existing riverine habitat and backwater areas more lacustrine in character. Smaller reservoirs occur on nearly every river and stream system in the state. Dams have also been built on many natural lakes to control water levels.

Fish communities in Wisconsin's lakes are generally typical of warm-water mesotrophic or eutrophic systems. They are dominated by native species, including largemouth bass, black crappie, northern pike, rock bass, and smallmouth bass. Common insectivores include bluegill, yellow perch, pumpkinseed, and johnny darter (Table 13). The most abundant omnivores are bluntnose minnow, golden shiners, white sucker, and common carp.

	Ecoregion				
Lake Type	Driftless Area	N. Central Hardwood Forest	Northern Lakes and Forest	SE WI Till Plains	All
Seepage					
Number	164	1,837	5,966	404	8,371
Total Acres	1,106	28,253	95,864	8,790	134,013
Drainage					
Number	132	922	2,715	255	4,024
Total Acres	27,548	34,375	146,316	10,494	218,733
Impoundment					
Number	261	447	601	239	1,548
Total Acres	39,249	159,974	213,043	253,749	666,015
All					
Number	557	3,206	9,282	898	13,943
Total Acres	67,903	222,602	455,223	273,033	1,018,761

Table 12

Number and area of Wisconsin lakes, by ecoregion as defined by Omernik and Gallant (1988), based on nearest county boundary.

NOLF Northern Lakes and Forest
NCHF North Central Hardwood Forest
DRFT Driftless Area
SETP Southeast Wisconsin Till Plains

Table 13

Comparison of percent fish species occurrences at stations in Wisconsin lakes. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Lake Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Top Piscivores					
Largemouth bass	59.5	66.5	95.5	49.8	67.8
Black crappie	17.3	38.3	31.8	27.3	28.7
Northern pike	21.7	20.8	22.7	13.0	19.6
*Rock bass***	*21.4*	*20.8*	*9.1*	*11.4*	*15.7*
*Smallmouth bass***	*12.6*	*16.9*	*18.2*	*6.4*	*13.5*
Insectivores					
Bluegill	66.7	79.2	68.2	72.2	71.5
Yellow perch	72.0	70.7	36.4	56.7	58.9
Pumpkinseed	43.9	53.0	27.3	51.1	43.8
Johnny darter	44.1	38.9	40.9	20.4	36.1
Logperch	11.5	16.6	40.9	10.2	19.8
Spotfin shiner	2.3	7.9	45.5	11.9	16.9
*Iowa darter***	*32.3*	*21.7*	*0.0*	*13.3*	*16.8*
*Blacknose shiner***	*23.3*	*9.0*	*0.0*	*15.2*	*11.9*
Green sunfish	2.1	8.5	9.1	26.9	11.6
*Spottail shiner***	*7.6*	*3.1*	*27.3*	*7.2*	*11.3*
Common shiner	14.7	15.8	4.5	5.6	10.2
Banded killifish	8.2	11.5	0.0	18.6	9.6
Brook silverside	5.3	1.7	9.1	21.3	9.3
*Blackchin shiner***	*15.2*	*12.1*	*0.0*	*9.2*	*9.1*
Black bullhead	8.8	7.3	4.5	13.5	8.5
Mimic shiner	14.8	4.5	0.0	10.4	7.4
Orangespotted sunfish	0.0	0.0	27.3	1.5	7.2
Brown bullhead	3.9	11.3	0.0	7.2	5.6
Emerald shiner	0.2	2.5	4.5	13.2	5.1

Continued on next page

A variety of herptiles inhabit lakes throughout the state (Table 14). Some amphibians use lakes, particularly their shallow bays, for reproduction. In many instances these are marginal breeding habitats with the exception of species dependent on permanent water, such as the bull, green, mink, and Blanchard's cricket frogs. The totally aquatic mudpuppy lives its entire life on the bottom of lakes, usually in deep water (Vogt 1981). All other Wisconsin amphibians rely on ephemeral waters for primary production. Five species of turtles occupy natural lakes including the state-threatened Blanding's turtle. While all five also occupy streams and rivers, all but the eastern spiny softshell are most productive in lake environments. All but the common musk turtle, which is limited to the SETP and DRFT ecoregions, are found in all ecoregions of the state.

Table 13 (cont'd)

Comparison of percent fish species occurrences at stations in Wisconsin lakes. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level[***] and Species	Percent of Sampled Lake Stations, by Ecoregion				
	NOLF[*]	NCHF[*]	DRFT[*]	SETP*	Average
Omnivores					
Bluntnose minnow	55.3	55.5	45.5	50.9	51.8
Golden shiner	24.8	21.4	27.3	23.1	24.1
White sucker	25.8	21.4	13.6	11.4	18.0
Common carp	0.2	6.2	31.8	12.2	12.6
Fathead minnow	11.2	15.8	9.1	8.7	11.2
Bullhead minnow	0.0	0.6	13.6	0.2	3.6
Total stations sampled	660	357	22	624	1,644

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains
**Italics indicate a fish species intolerant of environmental degradation, as defined by Lyons (1992)
***Trophic level as defined by Lyons (1992)

The macroinvertebrates of Wisconsin's inland lakes have not been intensively studied at a statewide scale. Preliminary indications suggest that species of Chironomidae would make up 75% or more of the taxa for most lakes (Richard Narf, Wis. Dep. Nat. Resour., pers. comm.). Most species of Hemiptera, Coleoptera, and Diptera occur solely or predominantly in inland lakes. There are no federal or state endangered or threatened aquatic insects for which inland lakes form primary habitat.

Rivers and Streams

Wisconsin's rivers and streams do not form distinct trophic states. Energy systems and species assemblages typically form a continuum from smaller, upstream headwaters to larger, downstream rivers (Vannote et al. 1980, Minshall et al. 1985). Rivers and streams may be classified into orders according to the number of branches or divisions from their mouth to their source (Strahler 1957). Lyons et al. (1988) showed that there is considerable gradation of fish

Table 14

Herptile species occurring in Wisconsin lakes, classified by ecoregions as defined by Omernik and Gallant (1988).

Species Name	NOLF[*]	NCHF[*]	DRFT[*]	SETP[*]
Blue-spotted salamander[**]	▲	▲	▲	▲
Central newt	▲	▲	▲	▲
Eastern tiger salamander[**]	▲	▲	▲	▲
Mudpuppy	▲	▲	▲	▲
Spotted salamander[**]	▲	▲		▲
Blanchard's cricket frog[E]			▲	▲[H]
Bullfrog[SC]	▲	▲	▲	▲
Cope's gray treefrog[**]	▲	▲	▲	▲
Eastern American toad[**]	▲	▲	▲	▲
Eastern gray treefrog[**]	▲	▲	▲	▲
Green frog	▲	▲	▲	▲
Mink frog	▲	▲		
Northern leopard frog[**]	▲	▲	▲	▲
Spring peeper[**]	▲	▲	▲	▲
Western chorus frog[**]	▲	▲	▲	▲
Blanding's turtle[T]	▲		▲	▲
Common snapping turtle	▲	▲	▲	▲
Common Map turtle	▲		▲	▲
Common musk turtle			▲	▲
Eastern spiny softshell turtle	▲	▲	▲	▲
Western/Midland painted turtle	▲	▲	▲	▲
Northern water snake	▲	▲	▲	▲

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains

** = Breeding Habitat Only
E = State Endangered
T = State Threatened
SC = Special Concern
H = Historic

A diverse system of headwater streams and tributaries feed into larger streams and rivers throughout the state. Shown here is Mecan River in central Wisconsin, which supports a trout fishery and diverse macroinvertebrate community. *Photo by Staber Reese.*

species along Wisconsin's flowing water habitats. Rivers and streams may also be classified by water temperature into warm-water, cool-water, and cold-water systems. Species inhabiting these systems usually reflect the maximum tolerable temperature limiting the presence of various aquatic species.

In Wisconsin, rivers and streams are commonly classified by fish community types. Smaller, spring-fed headwater streams and some rivers in the northern part of the state can support a fish community with trout or salmon as the top fish predator. Smaller streams fed by surface water or located in the southern part of the state are typically warmer and support fish communities with smallmouth bass as the top fish predator. Larger rivers support only warm-water fish communities with smallmouth bass, walleye, largemouth bass, northern pike, or muskellunge as the top fish predators. Rivers and streams with trout or salmon are often classed as "cold-water" systems, while the other streams and rivers are often classed as "warm-water" systems. Cold-water systems are afforded special protection under state law.

Streams

This category includes rivers and streams with mean annual flows of 40 cms or less (Lyons 1992). A definitive inventory of Wisconsin's streams is not available, but Becker (1983) indicates that of the 33,000 miles of rivers and streams in the state, 9,561 miles are cold-water trout streams (Wis. Dep. Nat. Resour. 1980). Adequate natural trout reproduction occurs in only 37% of the state's cold-water streams. The status of warm-water fish populations on most warm-water streams is not well known.

Table 15

Comparison of percent fish species occurrences at stations in Wisconsin streams. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Stream Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Top Piscivores					
*Brook trout***	*46.5*	*32.0*	*15.9*	*3.4*	*24.5*
Northern pike	11.5	18.9	7.6	28.7	16.7
Brown trout	13.4	21.4	22.0	7.9	16.2
*Rock bass***	*11.3*	*18.7*	*3.7*	*14.0*	*11.9*
Largemouth bass	6.8	12.3	6.8	18.7	11.2
*Smallmouth bass***	*4.3*	*13.6*	*11.5*	*10.8*	*10.0*
Burbot	14.0	10.8	3.3	0.5	7.1
Black crappie	2.5	7.1	2.8	11.4	6.0

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Table 15 (cont'd)

Comparison of percent fish species occurrences at stations in Wisconsin streams. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Stream Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Insectivores					
Creek chub	62.1	57.6	62.4	49.1	57.8
Johnny darter	33.7	50.1	65.3	40.3	47.4
Common shiner	44.2	48.9	29.1	38.7	40.2
Central mudminnow	48.3	52.4	16.8	40.5	39.5
Brook stickleback	40.4	31.4	39.0	32.8	35.9
Blacknose dace	45.0	38.6	40.3	15.8	34.9
*Mottled sculpin***	*45.1*	*29.7*	*7.1*	*10.6*	*23.1*
Hornyhead chub	22.0	26.2	19.0	18.4	21.4
Fantail darter	5.4	19.1	30.4	14.6	17.4
Longnose dace	20.4	21.6	22.8	4.5	17.3
Black bullhead	6.8	18.8	5.2	35.5	16.6
Pearl dace	25.2	25.5	2.0	6.5	14.8
Blackside darter	9.3	26.6	10.8	10.1	14.2
Green sunfish	0.3	6.0	10.7	39.4	14.1
Pumpkinseed	6.2	19.7	4.1	21.4	12.9
Bigmouth shiner	0.8	8.8	26.0	12.9	12.1
Spotfin shiner	0.9	7.9	21.1	18.5	12.1
Bluegill	6.8	12.6	6.7	21.4	11.9
*Northern hog sucker***	*8.3*	*22.1*	*10.5*	*6.5*	*11.8*
Yellow perch	15.0	12.7	1.6	13.0	10.6
Shorthead redhorse	5.6	7.1	14.8	8.9	9.1
Yellow bullhead	2.8	6.6	2.3	18.2	7.5
Stonecat	1.0	7.9	8.7	11.4	7.2
Sand shiner	1.1	2.7	9.5	14.5	6.9
*Rosyface shiner***	*1.1*	*10.4*	*9.0*	*4.0*	*6.1*
*Blacknose shiner***	*10.3*	*10.2*	*0.4*	*2.9*	*5.9*
*Banded darter***	*0.4*	*10.9*	*6.2*	*5.8*	*5.8*
*Rainbow darter***	*0.8*	*11.9*	*1.9*	*4.8*	*4.9*
Finescale dace	12.5	2.3	0.0	0.1	3.7
Suckermouth minnow	0.0	0.1	10.2	3.9	3.5

Continued on next page

A wide variety of warm- and cold-water fish species are found in Wisconsin streams (Table 15). Common species include brook trout, creek chub, johnny darter, common shiner, central mudminnow, brook stickleback, blacknose dace, white sucker, bluntnose minnow, and fathead minnow.

Knowledge about macroinvertebrates of Wisconsin's streams is still at the descriptive stage where distributions of species are becoming reasonably well known for many

Table 15 (cont'd)

Comparison of percent fish species occurrences at stations in Wisconsin streams. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Stream Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Omnivores					
White sucker	60.8	70.3	70.3	70.8	68.0
Bluntnose minnow	12.0	29.6	42.1	42.2	31.5
Fathead minnow	16.0	30.2	30.3	40.4	29.2
Common carp	0.2	6.4	10.7	31.8	12.3
Golden shiner	7.3	10.6	4.0	13.4	8.8
Herbivores					
Central stoneroller	0.2	6.9	33.4	15.4	13.9
Brassy minnow	20.6	15.9	9.2	8.4	13.5
Northern redbelly dace	27.7	18.3	0.8	5.0	12.9
Southern redbelly Dace	0.0	1.9	20.3	13.7	9.0
*American brook lamprey***	*2.6*	*7.0*	*16.8*	*2.2*	*7.2*
Largescale stoneroller	5.9	15.4	2.5	3.8	6.9
Total stations sampled	1,317	1,079	1,586	1,433	5,415

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains

** Italics indicate a species intolerant of environmental degradation, as defined by Lyons (1992)
*** Trophic levels as defined by Lyons (1992)

orders but significant gaps in knowledge remain. Overall, the number of streams that have been studied in detail is small. No effort has been made to compare macroinvertebrate faunas among ecoregions. Aquatic arthropods can be used to evaluate the water quality of streams based on the tolerance of the taxa to organic and nutrient pollution (Hilsenhoff 1987). Most species of Plecoptera, Ephemeroptera, and Trichoptera are found solely or predominantly in streams. Two dragonflies, two mayflies, and one riffle beetle that inhabit streams and rivers are listed as state-endangered. Additionally, three dragonflies are listed as state-historical, suggesting they have been extirpated from Wisconsin waters.

Three state listed species of stream freshwater mussels, ellipse, rainbow shell, and slippershell, were once widespread in the DRFT and SETP ecoregions. Geographic ranges have decreased over 90% for these species. They are riffle species preferring clear, small, warm-water streams and have been negatively affected by sedimentation, dam construction, fish community manipulations, and point pollution discharges. They are now restricted to small reaches in watersheds where these effects have been minimal. The rainbow shell remains only in one five-mile reach of one of the most well preserved SETP streams and is in immediate danger of extirpation from effects of urban sprawl.

Several herptile species occupy streams in Wisconsin (Table 16). The queen snake exclusively inhabits streams and their riparian corridors in the SETP ecoregion. This state-endangered snake, while on the northern fringe of its range, has declined in recent history as a result of water quality degradation including sedimentation and turbidity. The specific microhabitat of this species in the stream, flat rocky substrate, has been inundated by sediments throughout much of its former range in southeastern Wisconsin. The Blanchard's cricket frog, dependent on stream habitat and Wisconsin's most endangered herptile, has seen a marked reduction in its range in Wisconsin and elsewhere throughout the northern limits of its distribution.

Large Rivers

Large rivers are those having a mean annual flow of 40 cms or larger (Lyons 1992). Wisconsin has 11 stretches of large rivers: the Mississippi River, the Wisconsin River below Tomahawk, the Chippewa River below the mouth of the Flambeau River, the St. Croix River below the mouth of the Clam River, the Fox River below the mouth of the Puchyan River and between Lake Winnebago and Green Bay, the Menominee River below the Highway 2/141 bridge, the Rock River below Lake Koshkonong, the Flambeau River below the confluence of the north and south forks, the Wolf River below Shiocton, the Black River in LaCrosse County, and the Red Cedar River below Menomonie. Most of these river stretches have been dammed to produce hydropower.

These large rivers support only warm-water fish communities. The most abundant large predators are northern pike, walleye, smallmouth bass, largemouth bass, channel catfish, and burbot (Table 17). Common middle trophic level species are bluegill, black crappie, yellow perch, rock bass, pumpkinseed, freshwater drum, and white bass. A large number of lower trophic level species have been found at sampled river stations, but the most common are spotfin shiner, shorthead redhorse, golden redhorse, sand shiner, emerald shiner, common carp, johnny darter, logperch, northern hog sucker, white sucker, silver redhorse, and bluntnose minnow.

Wisconsin's large rivers contain some of the highest freshwater mussel species richness remaining in North America. The Wisconsin River contains 42 taxa, and the St. Croix has 39. Some southern United States rivers contained more species but

The Mississippi River and Wisconsin River, shown here at their confluence, are the most dominant riverine features in the state. They are biologically rich and provide a major corridor for movement of species throughout the watershed and region. *Photo by Ken Beghin*

Table 16

Herptile species occurring in Wisconsin streams, classified by ecoregions as defined by Omernik and Gallant (1988).

Species Name	NOLF*	NCHF*	DRFT*	SETP*
Four-toed salamander**	▲	▲	▲	▲
Mudpuppy	▲	▲	▲	▲
Blanchard's cricket frog[E]			▲	▲[H]
Bullfrog[SC]	▲	▲	▲	▲
Green frog	▲	▲	▲	▲
Mink frog	▲	▲		
Pickerel frogs	▲	▲	▲	▲
Blanding's turtle[T]	▲		▲	▲
Common snapping turtle	▲	▲	▲	▲
Common musk turtle[M]			▲	▲
Eastern spiny softshell turtle	▲	▲	▲	▲
Western/Midland painted turtle[M]	▲	▲	▲	▲
Wood turtle	▲	▲		
Northern water snake	▲	▲	▲	▲
Queen snake[E]				▲

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains

** = Breeding Habitat Only
E = State Endangered
T = State Threatened
SC = Special Concern
M = Marginal Habitat
H = Historic

Table 17

Comparison of percent fish species occurrences at Wisconsin river stations. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Stream Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Top Piscivores					
Northern pike	54.4	36.0	23.0	38.5	38.0
Walleye	45.6	26.7	31.7	46.2	37.5
*Smallmouth bass***	*39.7*	*37.3*	*28.1*	*42.3*	*36.9*
Black crappie	22.1	21.3	42.0	34.6	30.0
*Rock bass***	*30.9*	*24.0*	*29.9*	*7.7*	*23.1*
Largemouth bass	4.4	13.3	42.9	19.2	20.0
Channel catfish	17.6	12.0	11.5	23.1	16.1
White bass	0.0	4.0	31.4	15.4	12.7
Burbot	32.4	9.3	0.6	3.8	11.5
White crappie	1.5	1.3	19.3	23.1	11.3
Sauger	0.0	5.3	22.4	11.5	9.8
Bowfin	2.9	2.7	11.2	7.7	6.1
Longnose gar	0.0	2.7	21.8	0.0	6.1
Yellow bass	0.0	0.0	6.6	15.4	5.5
Shortnose gar	0.0	4.0	10.9	0.0	3.7
Insectivores					
Spotfin shiner	51.5	70.7	67.4	50.0	59.9
Shorthead redhorse	52.9	44.0	37.8	42.3	44.3
Bluegill	16.2	37.3	58.6	42.3	38.6
Golden redhorse	63.2	40.0	16.3	15.4	33.7
Sand shiner	29.4	42.7	27.8	34.6	33.6
Emerald shiner	0.0	38.7	66.8	26.9	33.1
Johnny darter	29.4	32.0	41.4	15.4	29.5
Logperch	30.9	32.0	30.5	23.1	29.1
*Northern hog sucker***	*54.4*	*33.3*	*5.4*	*23.1*	*29.1*
Silver redhorse	52.9	34.7	13.0	11.5	28.0
Yellow perch	39.7	24.0	38.1	7.7	27.4
Common shiner	69.1	21.3	3.6	0.0	23.5
Mimic shiner	27.9	38.7	12.4	0.0	19.7
River shiner	0.0	6.7	53.2	7.7	16.9
Brook silverside	7.4	17.3	31.1	7.7	15.9
Pumpkinseed	2.9	6.7	29.3	23.1	15.5
*Spottail shiner***	*2.9*	*2.7*	*43.8*	*11.5*	*15.2*
Freshwater drum	0.0	8.0	33.8	19.2	15.3
River redhorse	29.4	24.0	1.5	0.0	13.7
Western sand darter	0.0	17.3	20.2	11.5	12.3

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Trophic Level[***] and Species	Percent of Sampled Stream Stations, by Ecoregion NOLF[*]	NCHF[*]	DRFT[*]	SETP*	Average
Hornyhead chub	41.2	2.7	0.9	0.0	11.2
Blackside darter	29.4	12.0	2.7	0.0	11.0
Greater redhorse[**]	*25.0*	*10.7*	*0.0*	*3.8*	*9.9*
Gilt darter[**]	*32.4*	*6.7*	*0.0*	*0.0*	*9.8*
Mooneye	0.0	14.7	16.3	7.7	9.7
Pugnose minnow	0.0	6.7	27.8	3.8	9.6
River darter	0.0	16.0	13.0	7.7	9.2
Smallmouth buffalo	0.0	8.0	13.3	15.4	9.2
Green sunfish	0.0	2.7	2.4	30.8	9.0
Spotted sucker[**]	*0.0*	*8.0*	*23.3*	*3.8*	*8.8*
Bigmouth buffalo	0.0	4.0	6.3	23.1	8.4
Blue sucker[**]	*1.5*	*9.3*	*7.6*	*11.5*	*7.5*
Black bullhead	4.4	4.0	0.9	19.2	7.1
Yellow bullhead	1.5	2.7	8.8	15.4	7.1
Bigmouth shiner	1.5	2.7	11.5	11.5	6.8
Slenderhead darter[**]	*10.3*	*5.3*	*3.3*	*7.7*	*6.7*
Tadpole madtom	1.5	1.3	18.1	3.8	6.2
Speckled chub[**]	*0.0*	*2.7*	*10.0*	*11.5*	*6.0*
Stonecat	5.9	0.0	1.8	15.4	5.8
Banded darter[**]	*0.0*	*6.7*	*3.0*	*11.5*	*5.3*
Silver chub	0.0	0.0	17.8	0.0	4.5
Orangespotted sunfish	0.0	0.0	17.5	0.0	4.4
Paddlefish	0.0	2.7	1.2	11.5	3.9
Creek chub	10.3	2.7	1.8	0.0	3.7
Longnose dace	14.7	0.0	0.0	0.0	3.7
Mud darter	0.0	0.0	10.3	0.0	2.6
Omnivores					
Common carp	8.8	33.3	40.5	46.2	32.2
White sucker	32.4	36.0	12.7	34.6	28.9
Bluntnose minnow	23.5	37.3	16.6	26.9	26.1
Quillback	8.8	25.3	37.8	23.1	23.7
Bullhead minnow	0.0	4.06	2.2	7.7	18.5
Golden shiner	7.4	9.3	29.0	3.8	12.4
Highfin carpsucker[**]	*0.0*	*13.3*	*8.5*	*15.4*	*9.3*
Gizzard shad	0.0	0.0	28.4	7.7	9.0
Fathead minnow	7.4	5.3	4.8	11.5	7.3
River carpsucker	0.0	2.7	10.9	7.7	5.3

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Table 17 (cont'd)

Comparison of percent fish species occurrences at Wisconsin river stations. Includes only fish species found at $\geq$ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Table 17 (cont'd)

Comparison of percent fish species occurrences at Wisconsin river stations. Includes only fish species found at ≥ 10% of stations in at least one region, as defined by Omernik and Gallant (1988).

Trophic Level*** and Species	Percent of Sampled Stream Stations, by Ecoregion				
	NOLF*	NCHF*	DRFT*	SETP*	Average
Herbivores					
Brassy minnow	17.6	8.0	5.7	3.8	8.8
*Mississippi silvery minnow***	*0.0*	*2.7*	*18.1*	*0.0*	*5.2*
Parasites					
Chestnut lamprey	48.5	14.7	3.9	3.8	17.7
Silver lamprey	1.5	10.7	3.6	7.7	5.9
Total stations sampled	68	75	331	26	500

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains

** Italics indicate a species intolerant of environmental degradation, as defined by Lyons (1992)
*** Trophic levels as defined by Lyons (1992)

many of these species have been eliminated. Many of Wisconsin's listed mussel species have been eliminated or reduced by water level manipulations, commercial harvest, chemical treatments, fish community manipulations, competition from exotics, channelization, dam construction, and point and nonpoint-source pollution.

A number of state and federally listed plants are aquatic or riparian, and are associated with river ecosystems. Wisconsin lists ten endangered, ten threatened and 36 species of special concern that are supported by river ecosystems.

A variety of herptiles are found in Wisconsin's rivers (Table 18) including the endangered Blanchard's cricket frog found in rivers in the DRFT and the threatened wood turtle found in rivers in the DRFT and NOLF ecoregions. Some of the larger rivers have endangered species of dragonflies. At times, these dragonfly species are limited to specific river reaches. Thus, they are vulnerable to changes in habitat from riprapping, dredging, and modifications of velocities due to bridge construction.

Wisconsin's large rivers contain some of the most diverse freshwater mussel species associations remaining in North America. The Wisconsin River contains 42 taxa, and the St. Croix has 39.

A number of state and federally listed plants are aquatic or riparian, and are associated with river ecosystems. Wisconsin lists ten endangered, ten threatened and 36 species of special concern that are supported by river ecosystems.

Past Status

Wisconsin's aquatic communities were shaped by the last glaciation. About 11,000 years ago, ice covered most of what is now Wisconsin, precluding the existence of aquatic communities (Bailey and Smith 1981). The cold and turbid glacial meltwaters draining through the DRFT would have eliminated all but the simplest cold-water communities. As the glaciers retreated, aquatic organisms recolonized Wisconsin's waters from the Bering (Lake Agassiz), upper Mississippi, and Atlantic refugia (Bailey and Smith 1981, Greene 1935, Stewart and Lindsey 1983). The glaciers receded and crustal rebound alternately opened and closed connections between drainages until about 6,000 years ago, when the current physical aquatic landscape emerged.

Quantitative surveys of Wisconsin's aquatic resources were not made until the early 1900s. Consequently, descriptions of Wisconsin's earlier aquatic communities must be deduced from knowledge of current aquatic community status; the few early, usually anecdotal, descriptions of aquatic resources in the state; the few existing paleological studies of aquatic organisms; information on the nature and scope of human activities that have occurred in the state; and our understanding of the impacts such activities can have on aquatic systems.

Like terrestrial systems, aquatic systems are subject to the effects of simplification and fragmentation. Most major simplification in Wisconsin has been caused by human activity, but natural phenomena such as drought and forest fires have temporarily simplified aquatic systems.

The aquatic resources of the state have been impacted and changed to varying degrees by human activities since the area was repopulated after the last glaciation. Major changes began in the period of logging and rapid agricultural development in the late 1800s and early 1900s and continued through the industrialization of the 1920s to the 1960s into the current residential and recreational development period.

Aquatic systems are subject to simplification and fragmentation impacts just as with terrestrial systems. Most major simplification impacts in Wisconsin have been caused by human activity, but natural phenomena such as drought and forest fires have temporarily simplified aquatic systems. The impacts of simplification have included extirpation of native species, reduced species richness, loss of top predator species, shifts toward more generalized-feeding or more disturbance-tolerant species, reduced community abundance, reduced genetic diversity, and community instability. Such impacts have commonly been caused by direct loss or degradation of habitat, but they have also resulted from more subtle causes such as well-intended management activities (like stocking or chemical treatment), invasions of exotic species, and commercial or sport fishing. Scientists are just beginning to understand the critical importance of flood events and subsequent aquatic-terrestrial interactions in floodplains in shaping the biota of major rivers (Junk et al. 1989). Channel and flow modifications have resulted in simplification of these natural processes.

Fragmentation of aquatic communities is obvious in cases such as dam construction, where migrations of fish or other organisms are blocked. In other cases, severe simplification such as channelization, dredging, or areas of poor water quality have effectively fragmented aquatic communities. Fragmentation isolates populations, thereby increasing the long-term probability of loss of genetic diversity or

Table 18

Herptile species occurring in Wisconsin rivers, classified by ecoregions as defined by Omernik and Gallant (1988).

Species Name	NOLF*	NCHF*	DRFT*	SETP*
Mudpuppy	▲	▲	▲	▲
Blanchard's cricket frog[E]			▲	▲[H]
Bullfrog[SC]	▲	▲	▲	▲
Green frog	▲	▲	▲	▲
Mink frog	▲	▲		
Pickerel frogs[M]	▲	▲	▲	▲
Blanding's turtle[T]	▲		▲	▲
Common map turtle	▲		▲	▲
Common musk turtle			▲	▲
Common snapping turtle	▲	▲	▲	▲
Eastern spiny softshell turtle	▲	▲	▲	▲
False map turtle	▲		▲	
Smooth softshell turtle			▲	
Western/Midland painted turtle	▲	▲	▲	▲
Wood turtle	▲	▲		
Northern water snake	▲	▲	▲	▲
Queen snake				▲

*NOLF = Northern Lakes and Forest
NCHF = North Central Hardwood Forest
DRFT = Driftless Area
SETP = Southeast Wisconsin Till Plains

E = State Endangered
T = State Threatened
SC = Special Concern
M = Marginal Habitat
H = Historic.

Past and Present Actions Causing Concern

- Dam Construction
- Point-Source Pollution
- Agriculture
- Non-Agricultural Nonpoint Source Pollution
- Timber Harvest
- Channelization and Clearing of Streams
- Invasion of Exotic Species
- Riparian Development
- Fish Stocking and Poor Understanding of Genetic Diversity
- Large-Scale Chemical Treatment
- Department Management Priorities
- Habitat Improvement Projects
- Water Level Manipulations
- Estuary Habitat Management
- Lack of Monitoring
- Bioengineering
- Recreation

extinction due to random events. Fragmentation has isolated migratory species from necessary spawning, nursery, or adult habitat. Fragmentation has also interfered with recolonization of aquatic communities suffering from simplification impacts, even after the impacts are corrected.

Past and Present Actions Causing Concern

Dam Construction

Over 3,700 dams of varying sizes have been built on Wisconsin's rivers and streams. During the logging period, permanent and temporary dams were constructed to provide power for saw mills and increased water flow to float logs downstream. These dams were built on almost all major Wisconsin rivers, including the Chippewa, Flambeau, Black, Wisconsin, Peshtigo, Menominee, Oconto, and Iron rivers, and on numerous smaller streams. In the southern part of the state, dams were constructed to operate grain mills or for navigation.

In later years, many of the larger dams were converted to hydroelectric generation to supply power for the paper mills that grew up along the rivers or to generate electricity for residential or industrial use (Stark 1988). Smaller dams were maintained or constructed to create reservoirs and associated lakefront property, control water levels in natural lakes, or control floods. Water level control structures were built in low-lying areas such as Horicon Marsh to create and maintain wetlands for waterfowl habitat. A series of large dams and reservoirs was constructed on the Mississippi River to maintain a navigation channel for barges.

Dams have allowed humans to harness the power of water and have provided recreational benefits in the form of reservoirs. However, dams can simplify and fragment river habitats in a number of ways. *Photo by F. Albert.*

Dam construction can simplify and fragment river habitats in a number of ways. Most obviously, dams change riverine (lotic) habitat into lake or reservoir (lentic or lacustrine) habitat. Since dams are generally built in areas where rivers have a steeper vertical drop, higher gradient riffles and rapids are eliminated. Reservoirs created by dams can increase water temperatures and reduce dissolved oxygen levels in water discharged below the dam. Dramatic changes in stream flow patterns can disrupt spawning of native fish, reduce macroinvertebrate habitat, and increase erosion (Tyus 1990). Meffe (1991) and Winston et al. (1991) showed losses of native species in a river system after impoundments were built. Martinez et al. (1994) documented that even small-scale impoundments that do not radically alter hydrologic or thermal regimes can still have a strong negative influence on native fish by facilitating establishment and proliferation of non-native species.

Dams also interfere with the natural flooding and sediment transport patterns in a river. Natural flooding and sediment flow patterns include periods of scouring and sediment deposition that maintain the complex gravel riffle, pool, run river habitats, and seasonally provide rich nutrients to floodplain areas. Disruptions of these patterns can result in loss of riffle and pool habitat, depletion of nutrients in floodplain areas, and loss of sandbars. Sedimentation in upper reaches of reservoirs can greatly alter wetland areas. Dams interfere with the natural downstream transport of woody debris which forms important habitat for macroinvertebrates, fish, and other aquatic organisms. Logs, brush, and other debris that naturally enter river systems from riparian sources accumulate behind dams leaving downstream areas without this habitat.

Dams are typically impassable to upstream migration and pose mortality threats to downstream-migrating species. The few fish ladders which do exist are old and largely ineffective. No Wisconsin dams are equipped for downstream fish passage so migrating fish are exposed directly to mortality in turbines or spillways.

Dams alter contaminant dynamics within aquatic systems. Spring high flows flush contaminated water and sediments from basins. Blockage of this cleansing can cause accumulation within the reservoir particularly at the dam base. Contaminants in the collected sediments are then available for resuspension in the water column or uptake by bottom-feeding species. The upstream flooding of riverine wetlands produces elevated methyl-mercury in mercury contaminated systems (Zillioux et al. 1993).

In Wisconsin, dam construction and operation has had major impacts on fish. Becker (1983) noted that the gilt darter has been affected by dams because its preferred habitat, which is the large, fast-flowing sections of rivers, has often been used as dam sites. Eddy and Underhill (1974) regarded the gilt darter population in the Saint Croix River as a “modern relict population which has been isolated in recent times by habitat modifications in its former range.” The river redhorse, a state-threatened species, is declining in much of its range due to dam construction (Becker 1983).

Fish such as the paddlefish, lake and shovelnose sturgeon, blue sucker, and skipjack herring and several mussel species dependent on these fish for glocidial hosts are examples of species whose range has been dramatically altered by dams (Becker 1983). According to Helms (1974), populations of shovelnose sturgeon have been reduced in the Mississippi River due to habitat destruction resulting from several improvements to the navigation dams and channel civil works. Now shovelnose sturgeon are restricted to areas immediately below navigation dams. Construction of the Keokuk Dam on the Mississippi River (Lock and Dam 19 near Keokuk, Iowa) presented a barrier to extensive upstream

Applying the Ecosystem Management Decision Model to Aquatic Communities

The list of past and present actions causing concern for aquatic communities is lengthy, and the items on the list are complex and interrelated. All together, they point to the many dimensions of the human relationship to water. It is a resource that connects us in a myriad of seen and unseen ways to the components of the ecosystems upon which we depend. How will we make decisions that recognize the role of humans as part of aquatic ecosystems and at the same time fully protect them for future generations?

One positive step we can take is to begin to use and refine the ecosystem management decision model described in the second chapter. This model provides a series of questions that managers can ask to approach decision-making from three perspectives: the ecological, socio-economic, and institutional. Our success as resource stewards is a function of our ability to understand, analyze, and integrate alternatives across all three. The conservation of biological diversity is one of the threads that weaves throughout the model as it is applied to the array of actions that humans take to affect aquatic communities.

The questions and considerations for managers to use to address each of the three contexts are listed in the second chapter. However, there are two that deserve highlighting here. First, it is important that we apply the model on the landscape scale so that recommendations are made using the appropriate geographic boundaries. This will help us ask and answer the kind of broad regional questions that will guide the management of individual lakes. For example, how many lakes of different types are present in a region; what is their past, present, and potential future condition; and what strategies are needed to conserve biological diversity and provide for the range of human uses?

Second, it is clear that DNR is not alone in this work; success will be measured by our ability to identify and include stakeholders and to foster innovative partnerships with other agencies, local governments, and private interests.

migration of paddlefish, American eel, skipjack, Ohio shad, buffalo, shortnose gar, freshwater drum, carp, shovelnose sturgeon, and three species of catfish (Carlander 1954). The dam interfered with sauger movement during the winter, and spawning areas were cut off for the skipjack herring, the Ohio shad, and the blue sucker. The skipjack herring is the glocidial host for the ebony shell and elephant ear mussels. When the herring was extirpated from Wisconsin by construction of the Keokuk dam, the ebony shell and elephant ear mussels became endangered in Wisconsin occurring now only as scattered, old-age individuals (Becker 1983).

Becker (1983) reported that the paddlefish has also been affected by the construction of dams and flood control projects that flood its spawning areas. It was once abundant in Lake Pepin, where its numbers are now considerably reduced. Lyons (1993) noted that paddlefish could not recolonize areas above the Prairie du Sac dam on the Wisconsin River following water quality improvements because the dam prevented upstream movement. Heath (1993*a*) found that at least five mussel species were prevented from upstream recolonization through the same dam.

Becker (1983) made similar observations about the lake sturgeon. He noted hydroelectric dams act as barriers to movement of lake sturgeon, isolating their populations. Since lake sturgeon are long-lived but reproduce slowly, they may persist in an area for a long time, but they are susceptible to pollution, angler exploitation, poaching, and natural morality. Thus they may gradually die out without a source of adequate natural reproduction. High spring flows through the gated section of the dams tend to attract spawning lake sturgeon, inducing some to drop their eggs. Flows through the gates may later be shut, trapping the larger lake sturgeon behind boulders, in plunge pools, and behind riffles (Joseph Kurz, Wis. Dep. Nat. Resour., pers. comm.). Any eggs that were deposited are then exposed to the air and eventual desiccation. The adults are subject to eventual death due to exposure or poaching. Lake sturgeon have also been killed by hydroelectric equipment (Tom Thuemler, Wis. Dep. Nat. Resour., pers. comm.) and found entrained on dam trash racks (Tim Larson, Wis. Dep. Nat. Resour., pers. comm.).

Dams have had an even more dramatic impact on Wisconsin freshwater mussel populations. Mussels often congregate immediately below dams. Dams act as barriers to upstream fish movement and fish are more likely to drop the mussels' parasitic glocidial stage in areas immediately below the dams (Robert Martini, Wis. Dep. Nat. Resour., pers. comm.). The increased velocities through the reach below the dams may help scour the mussel beds clean of sediments. The upstream reservoirs probably also help to supply algae, diatoms, and other microscopic organisms that are food for filter feeders such as mussels (e.g., Ney and Mauney 1981), some of which are very old. The concentration of these fish and mussels, however, makes them susceptible to exploitation. Recently, the high price of mussel shells in Japan has resulted in intensive mussel harvest and subsequent closure of the mussel season in Wisconsin inland waters.

Hydroelectric facilities that conduct peaking operations (varying flows to produce electricity for peak demand periods) have an effect on downstream habitats. The availability of stream habitat is largely a function of stream discharge (Trotzky and Gregory 1974, Milhous et al. 1981, Bovee 1982, Bain et al. 1988, Leonard and Orth 1988). Changes in discharge translate into changes in substrate, velocity, and depth conditions. These flow-dependent physical habitat features play an important role in governing the distribution and abundance of mussels (Salmon and Green 1983, Neves and Widlak 1987, Way et al. 1990, McMahon 1991, Strayer and Ralley 1993); consequently, hydroelectric peaking operations can influence the availability of mussel habitat by creating wide fluctuations in discharge. Erosion and sand and silt deposition have been implicated in decimation of mussel beds on the Mississippi River (Stansbery 1970). Recent surveys by David Heath (Wis. Dep. Nat. Resour., pers. comm.) indicate the only known population of winged mapleleaf mussel exists in the St. Croix River below the St. Croix Falls hydroelectric dam, where it is subjected to periodic exposure and desiccation due to water level manipulation.

Dams constructed to alter water levels on natural lakes can change the aquatic plant community. Large scale changes in aquatic plant communities, riparian and littoral zone habitat, and water quality have occurred at least in part because of these artificial water level manipulations. Changes in water levels following dam construction have destroyed wild rice beds on some waters (Vennum 1988). The Army Corps of Engineers has attempted to maintain a stable level in the Great Lakes in accord with an agreement with Canada; however, the wetlands, spits, and sand beaches of the Great Lakes are shaped by natural fluctuations in water level. The coastal marshes concentrate much of the biodiversity and productivity in the Great Lakes and short- and long-term lake level fluctuation cycles are critical for sustaining the plant communities (Keddy and Reznicek 1986, The Nature Conservancy 1994). When the operating levels of the Great Lakes were set, it is unlikely that consideration was given to the environmental features that would be affected. The level of Lake Winnebago, the state's largest inland lake, is also controlled by dams.

The construction of dams and the associated control of flood waters may affect the reproductivity of amphibians within the floodplain ecosystems of dammed rivers. In free flowing rivers, spring snow melts and rainstorms can add considerably to flow levels resulting in frequent flooding of lowland areas adjacent to the river corridor, providing added capacity for amphibian reproduction in the form of ephemeral ponds. Most of Wisconsin's amphibians require ephemeral, fishless ponds for reproduction (Vogt 1981). The hydroperiod of ephemeral waters has a direct influence on both the diversity and abundance of metamorphosing juvenile amphibians (Pechmann et al. 1991). In drought years especially, the input to ephemeral ponds from early spring snow melt and subsequent flooding may be essential for amphibian recruitment. Dams can and often do eliminate or minimize the opportunity for flood water to benefit amphibians. The ecological effect of reduced amphibian reproduction may be significant since amphibians generally represent high levels of biomass in deciduous forests (Burton and Likens 1975), a habitat often associated with floodplains. The creation of dams has also converted many seasonal wetlands to more permanent water within the reservoirs. This is especially evident on the Mississippi River. Although these flooded wetlands are more productive fishery waters, amphibian populations are reduced. The magnitude of losses of amphibian populations caused by flooding wetlands is unknown.

Extensive dam construction in Wisconsin has reduced the available habitat for riverine reptile populations, but the total impacts are unknown. Painted and snapping turtles, which normally occupy slow flowing or standing water environments, may displace riverine species like wood or map turtles in reservoirs. Impacts to amphibians by damming can also have direct impact on reptile species dependent on amphibians for food. For example, the diets of garter snakes and northern water snake consist primarily of frogs (Vogt 1981).

Aquatic insect communities in the presence of dams are qualitatively different and usually less stable than those in unregulated stream sections. The presence of an impoundment changes the habitat and quantity and quality of food released in downstream areas. Hydroelectric peaking operations result in large and rapid fluctuations in flows below dams (Cushman 1985) which can reduce species diversity, density, and biomass of aquatic insects in tailwaters, with certain taxa affected selectively (Fisher and LaVoy 1972, Trotzky and Gregory 1974, Williams and Winget 1979). Specific problems include increased drift rates, which are known to accompany extreme changes in flow (Radford and Hartland-Rowe 1971, Beckett and Miller 1982), and stranding of stream insects in "intertidal zones" as waters recede (Kroger 1973, Ward 1976, Extence 1981). Additionally, more time is required for aquatic insects to colonize habitats in rapidly varying flows than in unregulated flows (Gersich and Brusven 1981). Lentic insects have replaced lotic insects in impoundments resulting in net losses of lotic forms (Neel 1963, Hilsenhoff 1971, Ward 1976). Changes in energy processing in impoundments has usually led to substantial densities of collectors and collector-gatherers in tailwaters but low densities of shredders and predatory insects (Spence and Hynes 1971, Simmons and Voshell 1978).

Few new dams are being built at this time, but renovation and expansion of existing dams is common. The late 1980s expansion of the dam at Jim Falls in Chippewa County created the state's largest hydroelectric facility. Recent interest in renewable energy sources has lead to an increased number of hydroelectric development applications with the Federal Energy Regulatory Commission (FERC). Hydroelectric power is a "clean" energy source because it produces no air emissions or solid wastes. However, we do not have a complete understanding of the impact of dam construction on biological diversity in the affected river, although there is substantial evidence that modifications of the natural flooding and sediment transport cycles in river systems can dramatically simplify these systems. The Department may need to prepare to deal with the potential influx of hydropower development license requests.

Under current FERC regulations, hydroelectric facility owners/managers are required to give equal consideration to the resource as is given to power generation. This is a boost for environmental protection of riverine ecosystems, especially compared with past regulatory requirements for hydro facilities. The Department is obtaining valuable information about endangered and threatened species and working with hydro owners/managers to work out agreements to better protect the resources affected by their operations. Wherever possible these hydroelectric facilities are encouraged to go to a run-of-the-river flow regime in an attempt to reverse effects of past peaking operations. At a minimum, studies should be undertaken to determine the minimum levels of flow necessary to protect the flora and fauna of these rivers while still allowing hydro facilities to utilize this public resource. Some successes have been achieved, both through the regulatory process and by working cooperatively with the hydro owners/managers. The results are expected to benefit a variety of species, including mussels, other aquatic invertebrates, amphibians, and fish. Dam relicensing and regulation activities rarely consider abandonment as meaningful options, and funds to remove dams are limited.

Dam operation on the Mississippi River and associated commercial barge navigation continues to have impacts on that riverine ecosystem. Potential impacts include conversion of riverine habitat to lacustrine, modification of normal water levels, sediment resuspension, dredging and channelization, and increased recreational use (Holland and Huston 1984, Smart et al. 1985, Eckblad 1986, Holland 1987, Fremling et al. 1989). In recognition of some of these problems, the U.S. Congress established an environmental management program with the objective of restoring and monitoring habitat in the upper Mississippi River (Lubinski and Gutreuter 1993).

Dam construction has had many well-documented negative impacts on Wisconsin aquatic ecosystems, but it has also created additional reservoir habitat statewide. Balancing the widespread losses of riverine ecosystems with gains in lake habitat—of which Wisconsin already had a natural abundance—becomes a controversial proposition. Wildlife management activities that impound streams for waterfowl management often increase habitat for a variety of species, and have often been built on degraded or channelized wetlands.

However, such dams can still affect rivers and streams like any other dam. They may increase nutrient loading to the impoundment; disrupt movement of fish; change the character of existing wetlands from shrub, sedge, or wooded to predominately open water; and disrupt water and sediment movement. On a few lakes, the presence of large numbers of waterfowl leads to increased eutrophication through the deposition of their fecal material. Some flora, such as Fassett's locoweed, are intimately associated with specific lakes and their unique water level characteristics. Modifications of these fluctuations, changes in nutrient levels, or pesticide inputs from groundwater could threaten the existence of these plants.

> Many Wisconsin waters suffered severe simplification from the effects of industrial and municipal point-source pollution from the 1800s through the 1960s. Federal and state Clean Water legislation has led to dramatic improvements in water quality and the restoration of these aquatic communities. However, the accumulation of pollutants in sediments will remain a source of contamination to the biota for an extended period.

Point-Source Pollution

Many Wisconsin waters suffered severe simplification from the effects of industrial and municipal point-source pollution from the 1800s through the 1960s. Discharge of nutrient-rich sewage effluent reduces dissolved oxygen causing direct mortalities of fish and other aquatic organisms (e.g., Coble 1982). Discharge of toxic chemicals can also cause direct mortalities and lead to build-up of toxic materials in the aquatic system. Benthic invertebrate communities are simplified through loss of species sensitive to water quality and increased dominance of pollution-tolerant generalist species (Cuffney et al. 1984, Chadwick et al. 1986, Camargo 1992). Heavy metals and organic chemical pollutants can bioaccumulate in fish posing a threat to wildlife and human health (Kleinert et al. 1974).

Becker (1983) presents a discussion of this problem in Wisconsin which is otherwise not well documented. Paper and pulp mills concentrated along the Wisconsin and lower Fox Rivers were the major source of pollution discharging both nutrient-rich effluents and toxics such as mercury and polychlorinated biphenyls (PCBs). Untreated or poorly treated municipal sewage was a second major source of pollution in many river systems. Discharges of toxic heavy metals occurred in areas of heavy industrial development such as Milwaukee, Racine, and Kenosha counties, and in central Wisconsin (Konrad and Kleinert 1974). Impacts on Wisconsin's aquatic systems from point-source pollution have been severe in some areas. Aquatic life including fish and fish-eating birds suffered heavy mortality and reproductive impairment in the Wisconsin and lower Fox Rivers and in localized areas with heavy discharges (Becker 1983, Hauber 1989, Giesy et al. 1994).

Federal and state Clean Water legislation has led to dramatic improvements in water quality in these areas and major steps toward restoration of these aquatic communities. However, the accumulation of pollutants in sediments will remain a source of contamination to the biota for an extended period. Aquatic communities of the Great Lakes are particularly susceptible to substantial bioaccumulation of contaminants due to their long water-residence times. The approximate flush time in Lake Superior is 182 years; in Lake Michigan it is 106 years (Arimoto 1989).

Agriculture

Agriculture can have a dramatic impact on aquatic ecosystems. Aquatic systems are simplified by direct habitat destruction, erosion and sedimentation, hyper-eutrophication, and water quality degradation (e.g., Armour et al. 1991). Agricultural practices of particular concern are livestock grazing in riparian areas, plowing and tilling of erodible soils (particularly in areas of steep terrain such as the DRFT), concentrated nutrient runoff from barnyards and feed lots, pesticide and nutrient runoff from fields, loss of upland vegetation when forests and prairies are brought under cultivation, dredging and filling of wetlands, and channelization of streams. Almost all the agricultural chemicals in use are water soluble, resulting in high mobility by water transport and thus a significant water pollution problem with the potential for chronic effects on aquatic organisms (Sagar 1991).

> Agriculture can have a dramatic impact on aquatic ecosystems. Practices of particular concern are livestock grazing in riparian areas, plowing and tilling of erodible soils, concentrated nutrient runoff from barnyards and feed lots, pesticide and nutrient runoff from fields, loss of upland vegetation when forests and prairies are brought under cultivation, dredging and filling of wetlands, and channelization of streams.

Agricultural impacts on aquatic organisms in Wisconsin and other Midwestern states are also well documented. Karr et al. (1985) estimated that 44% and 67% of fish species have disappeared or become less abundant in major Ohio and Illinois river systems and cited agricultural pollution as having had the greatest impact. Erosion and sedimentation have degraded many stream channels, resulting in severe impacts to these and downstream aquatic communities. Sedimentation profoundly changes stream insect populations (Rosenberg and Wiens 1978, Newbold et al. 1980, Lemly 1982, Culp et al. 1986). Paleolimnological evidence from Lake Mendota suggests there was a dramatic increase in sedimentation and eutrophication after 1800, when agriculture began in the basin (Kitchell and Sanford 1992). Biological communities also became more unstable, suggesting increased perturbation of the aquatic community.

One of the rarest fish in the state, the bluntnose darter, may have been affected by increased siltation due to plowing of the prairies (Pflieger 1971). This species prefers quiet oxbows, ponds, and sloughs with mud, clay, and mixed sand and mud bottoms. The population of mud darter, another rare fish in Wisconsin, declined in Illinois, due to decreased river size and reduced flows (Smith 1968). Decreased river size and flows in Wisconsin could occur due to groundwater pumping, pumping for agricultural irrigation, or droughts. Greene (1935) recorded the least darter in southeastern Wisconsin but recent surveys (Fago 1992) have not found the species there. According to Becker (1983) this loss may be due to increased turbidity and habitat destruction caused by agricultural, domestic, and industrial pollutants.

Specialist fish have been the most severely impacted. For example, Becker (1983) notes the gravel chub is limited to the lower Rock River drainage of Wisconsin and states, “the habitat requirements of the gravel chub are so strict that populations are isolated and confined to special riffle areas with special bottom types.” This specialization has made it vulnerable to turbidity and siltation, which increased as a result of agricultural activities. The creek chubsucker has probably been extirpated from the southeastern part of the state, where it was at the northern end of its range in the Des Plaines River (Becker 1983). Becker (1983) believes erosion and habitat destruction in the watershed eliminated the remnant population of the creek chubsucker by the middle part of the twentieth century.

The Ozark minnow is noted by Becker (1983) to be absent from a number of locations where it was previously reported, apparently because it is intolerant of excessive turbidity and siltation. Most of the streams where the Ozark minnow was located are characterized by heavy agricultural use. Becker (1983) also reports the pugnose shiner, a state-threatened species, does not tolerate turbid conditions.

The state-endangered queen snake has also been impacted by erosion and sedimentation resulting from agriculture in southeastern Wisconsin. This species has a very specialized diet consisting almost exclusively of crayfish (Vogt 1981) and requires a micro-habitat consisting of flat rocks on the stream bed under which it forages and seeks cover (Wood 1949). Many of the streams once utilized by queen snakes have experienced heavy sedimentation resulting in a loss of exposed rocky stream bed and an associated reduction or loss of crayfish populations (Gary Casper, Milwaukee Public Museum, pers. comm.).

Agriculture also affects amphibian populations in more ways than just by eliminating or altering their critical breeding and foraging habitats. Frogs and salamanders have very thin, permeable skin and are vulnerable to chemical alterations of their terrestrial and aquatic environments. The eggs and larvae are especially susceptible. Amphibians are considered to be excellent indicators of environmental health. Extremely high mortality and developmental abnormalities for some species are the result of toxicity caused by agricultural chemicals in aquatic systems (Hazelwood 1970, Birge et al. 1980). The Blanchard's cricket frog, Wisconsin's most endangered amphibian, has seen a dramatic decline throughout its historic range (Minton 1972, Christoffel and Hay, Wis. Dep. Nat. Resour., unpubl. data). While no specific cause has been implicated, it is suspected that agricultural chemicals (e.g., atrazine) are, in part, responsible for this decline. Hylid frogs in general, such as the cricket frog, may be more susceptible to pesticides than other frog species (Sanders 1970, Birge et al. 1979). These agricultural impacts may also be magnified through bioaccumulation in amphibian prey sources (Hazelwood 1970, Sanders 1970, Birge et al. 1980, Hall and Kolbe 1980, Linder et al. 1990).

Non-Agricultural Nonpoint-Source Pollution

The U.S. Environmental Protection Agency (EPA) estimates that 50% of water pollution in the U.S. is from nonpoint sources (Barton 1978). A 1985 survey indicated that 36% of all Wisconsin's streams and rivers are affected to some degree by nonpoint-source pollution (Bergquist 1986*a*). Not all nonpoint-source pollution comes from agriculture; it also results from urban stormwater runoff, use of fertilizers and chemicals in urban areas, construction site erosion, poorly designed or leaking septic systems, and poor land management practices in non-agricultural developments. Surface nonpoint pollution can include nutrient runoff, erosion and sedimentation, and toxic substances. Loss of terrestrial

Not all nonpoint-source pollution comes from agriculture; it also results from urban stormwater runoff, use of fertilizers and chemicals in urban areas, construction site erosion, poorly designed or leaking septic systems, and poor land management practices in non-agricultural developments.

Nutrients from nonpoint pollution enter lakes and are recycled during spring and fall turn-over. Excessive plant growth and algae are often the result. *Photo from DNR files.*

vegetation in urban areas increases the amount and variability of runoff events contributing to flooding and erosion in downstream areas.

The addition of nutrients from nonpoint sources increases the nutrient loading of the lakes and artificially accelerates the eutrophication process. Once a lake is overloaded with nutrients, they are hard to remove, since the nutrients are continually recycled during spring and fall overturn. Increased nutrients cause increased algae or macrophyte growth. Excessive increases in plant growth are often dominated by a few species reducing aquatic plant species diversity. The proliferation of macrophytes into the entire euphotic area of the littoral zone leads to loss of small openings for fish spawning and creates an extreme amount of escape cover for young-of-the-year fish, which can become overpopulated and stunted. The resulting competition for limited food resources can adversely affect fish species and benthic organisms that may be either a food source or a competitor for food. Decay of the increased plant biomass when it dies can result in decreased dissolved oxygen levels and kills of fish and other aquatic organisms.

Changes in Wisconsin's aquatic systems caused by non-agricultural nonpoint-source pollution are less well documented than in agricultural areas, probably because they have been isolated in highly urban areas and masked by point-source and agricultural pollution problems. Since intense urbanization is a relatively recent phenomenon in most of Wisconsin, it is probable that urban nonpoint-source pollution has only recently been impacting aquatic ecosystems on a statewide scale. Except in a few isolated watersheds, rural and urban nonpoint-source problems have not been controlled. The state's major nonpoint-source abatement activity is the Priority Watershed program (Bergquist 1986*b*). The effectiveness of this program in achieving results has been questioned, and evaluation efforts have only recently been initiated (Simonson and Lyons 1992). New laws requiring storm water retention basins in new developments will help but do not address problems from existing development.

Contamination of groundwater and surface waters from abandoned landfills and leaking underground storage tanks continues. Inventory of these sites is incomplete, and their contents are often not known, but many may contain hazardous and toxic materials. The amount of contamination depends on the rate at which the site fails, the content of the site, its proximity to the aquatic resource, and the soils and geology of the area. However, since the groundwater gradients are generally in the direction of surface waters, it will only be a matter of time before the contaminated groundwater reaches a surface water.

Poorly designed and leaking septic systems can lead to water quality problems in unsewered residential areas. Lakefront development is of particular concern because of its proximity to surface waters and higher than normal density of septic systems. Lakefront developments are often in rural areas where connection to sewer systems is very costly. Elimination of nutrient inputs to lakes often does not improve water quality because previously added nutrients are concentrated in lake sediments and continuously resuspended and recycled.

Timber Harvest

The impacts of silvicultural activities in Wisconsin on water quality are not well studied. Timber harvest within watersheds and along riparian areas has been shown to affect water quality in other regions of the country through increased runoff, sedimentation, and temperature, and by reducing primary productivity and dissolved oxygen (e.g., Gray and Edington 1969, Hibbert 1969, Fredrickson 1970, Hornbeck et al. 1970, Hansmann and Phinney 1973, Beschta 1978, Pearce and Rowe 1979, Bernath et al. 1982, Hewlett and Fortson 1982, Lynch et al. 1984, Noel et al. 1986, Verry 1986, Hicks et al. 1991).

Large woody debris normally resulting from streamside bank erosion or blowdowns plays an important role in stream and river morphology, hydrology, and ecology. Bilby and Ward (1989) studied the relationship of woody debris to the size of streams in western Washington. Large pieces of woody debris influenced channel morphology there through bank erosion, channel scouring, deposition, sandbar formation, nutrient and organic material retention, and species composition. However, the larger the river, the larger the woody debris needed to overcome the capacity of the river to move the debris downstream. The mean diameter, length, and volume of woody debris increased as channel width increased. Murphy and Koski (1989) studied the rate of input and depletion of large woody debris in Alaskan streams. They found the rate of input and depletion was inversely proportional to the diameter of the debris. The model used predicted that 90 years after a clear cut, large woody debris would be reduced by 70%, and it would take 250 years to return to prelogging levels. They recommended a 30-m wide unlogged buffer strip next to streams to maintain large woody debris for input to streams. Benke et al. (1985) showed that although woody debris accounted for only 4% of habitat surfaces in a low gradient Georgia coastal stream, they supported 60% of the invertebrate biomass and 16% of the production for a river reach. Losses of habitat elements such as large woody debris can have effects for 80 to 160 years (Sedell and Frogatt 1984, Sedell and Swanson 1984, Minckley and Rinne 1985).

Although many of these studies are not specific to Wisconsin, the relationship between water quality and logging practices is important. Given the historical intensity of timber harvest in northern Wisconsin, it is likely that some forestry practices have had similar water quality and habitat reduction impacts in Wisconsin's aquatic systems. For example, Watermolen (1993*a*) lists some specific streams in the upper Green Bay basin that have been impacted by recent forestry practices.

Large woody debris such as this fallen tree plays an important role in stream and river ecology. *Photo by Betty Les.*

While most public lands have aesthetic management zones to maintain the visual appeal of an undisturbed shoreline, harvesting practices on the backlands can still lead to erosion and disruption of overland water flow. Wisconsin has developed a new program, Wisconsin's Forestry Best Management Practices for Water Quality, which will help address these concerns.

Channelization and Clearing of Streams

Streams have been straightened or channelized in the mistaken belief that hydraulic efficiency was better for the conveyance of flood waters brought on by runoff from pastures and intensively farmed cropland and denuded forest lands. Removal of natural obstructions to navigation have also been commonplace, particularly during the period when rivers were extensively used to transport logs. Channelization is known to reduce species richness and diversity in fish, aquatic invertebrates, and mussels, and to impact other organisms such as furbearers that depend on aquatic systems (Schneberger and Funk 1971, Yokley and Gooch 1976, Yokley 1977, Arner et al. 1979, Schlosser 1982, Kanehl and Lyons 1992). Further, it can often lead to the instream disposal of dredge spoils which is detrimental to aquatic life. Instream disposal directly affects fish reproduction, benthos and water quality (Morton 1977). The channelization and clearing of streams has eliminated entire reaches of valuable aquatic communities for warm water, cool water, and cold water species. Reduced amounts of large woody debris in streams can alter aquatic insect community structure, especially in rivers with a shifting sand bed (Dudley and Anderson 1982; Benke et al. 1984).

Channelization often results in the reduction of natural edge along aquatic corridors and also results in the disturbance of shoreline vegetation, opening the door for invading exotic plant species. Many of Wisconsin's herptile species rely on these riparian areas for a great deal of the active season for shelter and foraging (Vogt 1981). Channelization does not likely threaten most herptile populations but it is certain their numbers are reduced by it.

The establishment of exotic species or hybrids in an aquatic ecosystem may initially appear to increase species richness and diversity. However in the long term, invasions of exotics may result in the loss of native species and the disruption of habitats, predator-prey relationships, and energy flow processes.

The extreme impacts of channelization and dredging in Wisconsin's waters have been well documented. While these activities have been curtailed, permits are still sometimes issued. Smaller development or maintenance projects are still permitted by the state when the local regulator does not believe the environmental impacts outweigh the perceived benefits. Large navigation projects such as the Mississippi River are under federal control.

Invasion of Exotic Species

The establishment of exotic species or hybrids in an aquatic ecosystem may initially appear to increase species richness and diversity. However in the long term, invasions of exotics may result in the loss of native species and the disruption of habitats, predator-prey relationships, and energy flow processes. Exotic species often invade without the normal predators or parasites that control their numbers in their native ecosystems, and existing ecosystems may be unable to accommodate the new species without an overall simplification of the community. Introduced exotics are often disturbance-tolerant, hardy generalists having successfully survived human introductory mechanisms such as overseas shipping or passage through pre- and post-export chemical treatments. These hardy species are well adapted to exploit already stressed and over-simplified biotic communities. In some cases, exotics initially explode in numbers but eventually stabilize at a lower level of abundance. It is difficult to predict the impact that a new exotic species will have on an existing aquatic ecosystem.

Non-native species have frequently invaded or have been introduced to Wisconsin's aquatic communities. Several key exotics unintentionally gained access to the Great Lakes via the St. Lawrence Seaway, either transported in ballast water, attached to vessels (Moyle 1991), or by direct migration. Invader species include the Asiatic clam, the sea lamprey, river ruffe, white perch, *Bythotrephes* (a predatory cladoceran), and the zebra mussel. Other species have been intentionally stocked, including the common carp, which was brought in with the best of intentions in the late 1800s. The introduction of this species is the most infamous example of a management action that was thought to be beneficial at the time—but turned out to have devastating consequences (Courtney and Moyle 1992) which managers are still struggling to cope with today. Introduction of desirable species such as brown and rainbow trout have had unknown impacts on native brook trout. The grass carp, a more recent introduction, is now reproducing in the lower Mississippi River.

Exotics can also be introduced through releases of species used for bait. There have historically been few controls or monitoring of the harvest, transfer, or sale of fish or aquatic invertebrates used for bait (Threinen 1982). It is believed the rusty crayfish was accidently introduced from Illinois by bait anglers. The impacts of rusty crayfish on the communities in certain waters have been great (e.g., Olsen et al. 1991).

There are several well documented invasions of exotics in Wisconsin. Eurasian water milfoil was first discovered in Wisconsin in 1967 and has now spread to at least 75 lakes in 39 counties (Bode et al. 1993). The explosive growth of this plant can substantially alter native aquatic plant communities, interfering with recreational use, impacting fish communities, and choking water intakes.

The river ruffe is already the second most abundant species in the St. Louis River estuary, and biologists fear that it is a predator of whitefish eggs and that it can successfully compete against yellow perch (Moyle 1991). The white perch now found in Green Bay also has the potential to overtake the native yellow perch; however, several studies have not found such impacts in Oneida Lake, New York, or Lake Erie (Forney 1974, Schaeffer and Margraf 1987). Fuller (1974) considers the Asiatic clam to be a form of pollution itself. This species is a threat due to its free-swimming larva and its ability to exploit any available substrate though there is no evidence to indicate that the Asiatic clam can successfully compete against other clams and mussels in Wisconsin as it does in some southern states.

The zebra mussel has become established in Lake Michigan and the Mississippi River, and its numbers have significantly increased to date. This invader poses a significant threat to native mussels. Native mussel populations have already declined in some areas of the Great Lakes Basin due to the impacts of zebra mussels (Hebert et al. 1991; Mackie 1991). The potential impacts of zebra mussels on native bivalve populations have important implications for the upper Mississippi River, which has one of the most rich and diverse mussel populations in the world (Cope, U. S. Fish and Wildl. Serv., unpubl. data). In addition, zebra mussels have been identified as responsible for concentrating organochlorine pollutants and maintaining them in the food chain (Stone 1994).

The impacts of exotics on Wisconsin's aquatic ecosystems are difficult to assess. Intentional introductions of brown and rainbow trout, Pacific salmon, striped bass, and grass carp are often cited as examples of successful introductions of non-native species, but the long-term implications of these introductions are poorly understood. No exotic that has become established has ever been eradicated, so the risks associated with introducing exotics are extremely high. It is unlikely that any species have been extirpated from Wisconsin because of exotics, but it is probable that native species such as brook trout have been significantly reduced in abundance and distribution by competition from exotics (e.g., Waters 1983, Larson and Moore 1985). The invasions of carp, river ruffe, sea lamprey, alewife, zebra mussels, white perch, rusty crayfish, purple loosestrife, and Eurasian water milfoil have already had negative impacts on native ecosystems. Control of these invasions is already beyond the capability of any management agency. Management agencies across the country, however, continue to propose introduction of new exotics. Most states around Wisconsin have already allowed introduction of the grass carp for control of aquatic macrophytes with supposed safeguards against their becoming naturalized. Despite these safeguards, grass carp have successfully reproduced in the lower Mississippi River (Allen and Wattendorf 1987). Well-intentioned introductions of largemouth and smallmouth bass in Texas have led to genetic introgression with the endemic Guadalupe bass, which is now well on the way to extirpation in some river systems (Morizot et al. 1991).

Introductions of supposedly infertile sauger-walleye hybrids and stocking of sauger into native walleye waters have led to genetic introgression between the two species (Billington et al. 1988). Sauger-walleye hybrids have been stocked in some Wisconsin waters. North Dakota has already stocked zander, a close European relative of the walleye, into supposedly landlocked waters in the state (Terry Steinwand, pers. comm.). Its escape and establishment in native walleye waters would undoubtedly have a devastating impact on native walleye and sauger populations.

New regulations to control the introduction of exotics through Great Lakes ballast water exchanges have been proposed by the U.S. Coast Guard. Wisconsin has adopted new laws to eliminate the importation of exotic fish species. The Department has not allowed the use of grass carp and has taken steps to actively eliminate populations that were discovered. The Department has not proposed stocking other exotic species in recent years. In addition, the Department has undertaken public education programs designed to minimize spread of exotic organisms such as Eurasian water milfoil and Zebra mussel, and participated in monitoring programs for species such as purple loosestrife and Zebra mussel. Whether these actions will be sufficient to prevent the continued introduction of exotic species into Wisconsin waters is unknown, but recent history suggests far more rigorous efforts may be needed.

Left undeveloped, riparian areas provide food and habitat for species such as this great blue heron. *Photo by Bob Queen.*

Riparian Development

Riparian habitat along Wisconsin's lakes and rivers has been extensively developed since the mid-1800s. Shoreline development in populated southern areas occurred early in this period where people lived and worked. Development on northern lakes and rivers came later and was initially limited by the remoteness of the area and its sparse population. However, as wages and leisure time increased, as transportation improved, and as the state's population grew, more people were interested in second homes. Cottages, resorts, shacks, trailers, and all manner of dwellings were built. Before zoning laws existed, some structures were built only a few feet from the shoreline; trees and logs were cleared from both water and shore, and privies or septic systems were put in. The level land and sandy shorelines suitable for beaches on well-known lakes disappeared first, followed by development on less desirable land that was steeper, rockier, or marshier. Rates of development have continued to escalate in recent years. The number of lake front homes in Forest County, for example, has increased 700% during the last ten years. In the Brule area, development has increased 19% for 200-450 acre lakes and 78% for 100-124 acre lakes over the past 10-30 years (Korth 1993). Only a few isolated lakes escaped extensive development, including some large flowages such as the Turtle-Flambeau, Chippewa, Gile, Rainbow, and Willow, as well as small lakes or lakes on land owned by paper companies or public agencies such as the U.S. Forest Service, counties, and the Department.

With riparian development came extensive loss and simplification of aquatic habitats. Owners of lake property commonly modified the shoreline or littoral area adjacent to their property by using sand blankets, shoreline protection such as riprap and retaining walls, docks and piers, boat houses, dredging for access, aquatic plant nuisance control, and filling. Disruption of natural shoreline changed gradations in water depth in lakes, thereby eliminating natural formation of plant communities (Keddy 1983), and similar development along streams causes changes in the structure of the macroinvertebrate communities (Cummins et al. 1984, Sweeney 1993). Aquatic plant communities were frequently directly altered through mechanical removals or chemical treatments. Many alterations were done by specific riparian property owners, but some municipalities have operated large-scale aquatic plant control activities.

Isolated cases of shoreline modification may have little potential for affecting the aquatic community, but the cumulative effects of numerous alterations can have significant and long-lasting impacts due to habitat loss and simplification (Panek 1979). Some Wisconsin lakes, such as Shawano Lake, have very little natural shoreline left. Lyons (1989*b*) reported a significant simplification of the littoral zone fish community of Lake Mendota since 1900 and attributed the changes in part to increased shoreline development. Bryan and Scarnecchia (1992) found significantly fewer fish species and reduced abundance in developed shoreline areas in an Iowa lake. Miller et al. (1989) conclude that habitat alteration was a factor in 73% of fish extinctions in North America during the past 100 years. Kapuscinski and Jacobson (1987) explain that habitat alteration can impact genetic diversity by reducing the effective population sizes and changing selection pressures on previously well-adapted species.

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Lakes were also affected by the draining and filling of wetlands, which supported waterfowl, reptiles, and amphibians, northern pike, and muskellunge spawning areas. Loons, ospreys, eagles, otter, muskrat, and mink were all affected by habitat degradation and harassment resulting from increased use. Habitat loss and urbanization have been implicated in reducing populations of several dragonfly species that are threatened or endangered in Wisconsin (Nilles 1993).

The cumulative effects of numerous shoreline alterations may be detrimental to local amphibian and reptile populations (Watermolen 1993*b*). Many amphibian species dependent on the shoreline/water interface (e.g. green, mink, and bull frogs) are displaced when seawall construction replaces the natural shoreline. The greater the loss of natural shoreline the greater the impact to the local frog population. Aquatic turtles, which need to leave the water to lay their eggs on land, are affected by shoreline barriers. Several species of Wisconsin turtles show strong signs of nest site fidelity. When turtles are prevented immediate access to these sites because of shoreline development, they are forced to expend additional time and energy searching for a new site or travelling indirectly to their traditional site. This exposes them to potentially higher mortality since most aquatic species have little natural defense on land. What effect this has on populations is unclear.

Despite the well-documented negative impacts of riparian development, it continues on Wisconsin's waters at a rapid pace. There are few legal restrictions to development, a situation difficult to change because of the high demand for and value of lakeshore property. The Department controls permitting of erosion control structures and lake bed modifications, but such decisions are increasingly being challenged in legal forums. Increasing evidence also suggests that riparian activities beyond the ordinary high water mark, which are not controlled by the Department, have impacts on the systems. Research has been done in Canada to predict sustainable levels of lakeshore development (Dillon and Rigler 1975), but these methods have not been applied in Wisconsin. Filling of riparian wetland areas has been dramatically curtailed, but is still a concern.

Riparian areas are also increasingly impacted by beaver activities. Wisconsin beaver populations have been increasing in recent years due to elimination of natural predators, reduced trapping pressure, and habitat management practices that increase aspen and willow. Beaver activity can have a significant impact on riparian areas, including damming of streams, cutting of trees, and flooding of low-lying areas. While moderate levels of beaver activity are probably necessary to maintain native habitat patterns along streams, excessive levels are thought to disrupt fish movement, alter sedimentation patterns, and increase water temperatures, adversely affecting cold-water communities.

Fish have been artificially propagated and widely stocked in Wisconsin for more than a century. Fish have also been routinely moved from one water body to another, and new species have been widely introduced . . . . While these efforts reflected the best understanding of fish management at the time, there is growing evidence that stocking or transfers of fish can have long-term negative impacts on growth, survival, reproduction and even health of both the existing fish population and the newcomers.

Fish Stocking and Poor Understanding of Genetic Diversity

Fish have been artificially propagated and widely stocked in Wisconsin for more than a century. Fish have also been routinely moved from one water body to another, and new species have been widely introduced. The magnitude of the fish-stocking and transfer program in Wisconsin since 1874 is staggering. Virtually every major lake and river has been stocked at one time or another by the Department or private individuals. Becker (1983) presents an excellent summary of the evolution of the Wisconsin stocking program. By 1900, Wisconsin had attempted introductions of Atlantic salmon, chinook salmon, grayling, rainbow and brown trout, carp, and goldfish. Walleye propagation began in 1883 with production of eight million fry. Muskellunge propagation began in 1897 with production of one million fry. Hatching and stocking of lake trout, brook trout, and whitefish was done as early as 1876. In 1937, Wisconsin stocked over a billion fish of various species.

Currently the Department annually stocks on average about 615,000 brook trout, 2.2 million brown trout, 940,000 rainbow trout, 280,000 lake trout, 260,000 splake (brook trout x lake trout hybrids), 2.3 million chinook salmon, 659,000 coho salmon, 513,000 largemouth bass, 63,000 smallmouth bass, 169,000 muskellunge, 28,000 hybrid muskellunge (northern pike x muskellunge hybrids), 60,000 northern pike, 2,300 lake sturgeon, 3.5 million walleyes as fingerlings, yearlings, or catchable-sized fish. Another 65,000 largemouth bass, 850,000 muskellunge, 344,000 hybrid muskellunge, 15 million northern pike, 61,000 lake sturgeon, and 51 million walleyes are stocked as newly hatched fry. Other species stocked periodically include channel catfish, sauger and several species of panfish (Dave Ives, Wis. Dep. Nat. Resour., pers. comm.).

Trapping and transfers of adult fish was common from 1874 until the 1930s (Becker 1983). Fish were often "rescued" from waters expected to experience winterkill or from flooded backwater areas of the Mississippi River as they were stranded by receding flood waters in the spring. Rescued fish were transferred to waters across the state. In 1936, nearly ten million fish, including catfish, sunfish, crappies, bass, and buffalo, were trapped and transferred among various state waters. This activity became less common after 1940 but is still used in some winterkill and panfish management situations.

While these efforts reflected the best understanding of fish management at the time, there is growing evidence that stocking or transfers of fish can have long-term negative impacts on growth, survival, reproduction and even health of both the existing fish population and the newcomers. Largemouth bass moved between Texas, Florida, Wisconsin, and Illinois invariably showed significantly lower growth and survival in non-native waters (Philipp and Whitt 1991, Philipp 1991). Cutthroat trout stocking in Yellowstone was shown to have disrupted and reduced natural reproduction (Gresswell and Varley 1988). A comprehensive literature review examining releases of cultured salmonids into native populations concluded that, when effects were seen, they were always detrimental to the native stocks (Hindar et al. 1991). Hybridization, often resulting from stocking of different genetic strains, was a factor in 38% of fish extinctions in North America during the last 100 years (Miller et al. 1989). Hatchery fish can introduce poorly adapted genomes into the population and through introgression disrupt the genome of the existing naturally reproduced fish (Magnuson 1976). Introductions of different genomes caused by releases of bait fish can have the same effect.

Genetically different stocks may exist for many important fish species found in Wisconsin (Kapuscinski and Lannan 1986). Analysis of DNA pattern variations in walleye suggest that current stocks evolved from three distinct glacial refugia, and different walleye genetic types show clear regional distribution patterns (Billington and Hebert 1988). Genetic differences among walleye stocks have been documented within states (McInerny et al. 1991) and even within the same drainage (Todd 1990). Similar differences have been documented for largemouth bass (Philipp et al. 1983) and northern pike (Seeb et al. 1987). Only limited work has been done to analyze genetic variability among stocks in Wisconsin. The Department is currently funding a study of genetic differences among different spawning populations in the Lake Winnebago system. Preliminary results show limited allozyme variability (Treloar and Ehlinger 1991). The Department has also recently begun a major effort to quantify the genetic differences among watersheds for an additional eight warm-water species and native brook trout.

Fish stocking and transfers can also impact biodiversity by introducing new species into aquatic communities, with resulting changes in the relative abundances of the native species. Walleye, for example, is not native to small seepage lakes in Wisconsin (Becker 1983), but this species is now found in almost every such lake more than 200 acres in size. The impact of these introductions on the existing aquatic community is not well understood, but Colby et al. (1987) document fish community changes resulting from species introductions. In Wisconsin, for example, introduction of walleye and northern pike into Escanaba Lake resulted in long-term declines of smallmouth bass and panfish populations (Kempinger et al. 1975).

Release of bait fish and macroinvertebrates is another source of genetic mixing. Bait species are commonly harvested from naturally occurring populations and transferred to other waters for sale and potential release. Cultured bait species are also commonly sold but suffer the same potential genetic disruption as that caused by any other hatchery-reared species. The bait industry in Wisconsin is lightly regulated and little information is collected on the origin of fish that are sold.

Some species, such as walleye and lake trout, exhibit homing instincts during spawning. Walleye and lake trout also seem to exhibit spawning preferences and requirements unique to specific strains. Whether stocking of hatchery-reared fish has already affected this behavior is not known. In addition to the genetic effects of stocking, stocking large numbers of hatchery-reared fish among relatively few naturally reproduced fish can subject the natural population to increased fishing pressure because fishing gear is nonselective.

The actual impacts of fish stocking and transfer activities on Wisconsin's aquatic communities can never be fully known. However, given the magnitude of the number of fish and waters stocked, and the likelihood of genetic and population changes, it is probable that there have been significant changes in species abundances and distributions across the state. Becker (1983) suggests many anomalous distribution records may be due to these activities. Certainly the distribution of some major game species such as walleye, muskellunge, brown trout, and rainbow trout have been dramatically increased, but it is also likely that species such as largemouth or smallmouth bass and brook trout that existed prior to the introductions have suffered a corresponding decline in abundance and distribution. Changes in lower trophic level species are undocumented. Genetic impacts of stockings of species in waters where there were already naturally reproducing populations of those species are unknown, but it is likely that some populations have suffered declines in natural reproduction.

This evidence has led to numerous recommendations against mixing different genetic stocks. After an extensive survey of salmonid stocking effects, Hindar et al. (1991) recommend "strong restrictions on gene flow from cultured to wild populations and effective monitoring of such gene flow." In a reference work on fisheries genetics, Kapuscinski and Jacobson (1987) recommend managing to avoid stocking and, when necessary, stocking only locally adapted fish. Both Meffe (1987) and Kapuscinski and Philipp (1988) conclude that significant problems in conserving existing levels of genetic diversity exist and that additional cooperation and research will be needed to determine appropriate management strategies. The American Fisheries Society has developed a draft position statement entitled "Protecting Native Fish Stocks: The Elimination of Stock Transfers," which advocates a stock concept of management and restrictive stocking and stock transfer policies designed to protect native stocks (Philipp et al. 1991).

Population changes caused by long-term or size-selective harvest have often been shown; however, genetic changes are poorly documented (Policansky 1993). Highly selective gillnet fisheries were implicated in long-term changes in lake whitefish growth rate, condition factor, and mean age (Handford et al. 1977). High exploitation rates have changed growth and mean age in lake whitefish and walleye populations (Healey 1980, Reid and Momot 1985, Mosindy et al. 1987). Nuhfer and Alexander (1991) conclude that long-term angling exploitation may alter the genetic composition of wild brook trout strains.

Stocking and stock transfers remain important management practices in Wisconsin. Adult stock transfers of northern pike and various panfish species between waters and watersheds still occur. Current Wisconsin hatchery practices and stocking policies do not consider genetic conservation. For example, virtually all walleye and muskellunge hatchery production comes from the Spooner and Woodruff hatcheries—both located in far northern Wisconsin. All spawn is taken from local lakes, but the hatched fish are distributed throughout the state. Wisconsin also periodically exchanges hatchery products with other states and federal agencies.

Today, managers are increasingly less interested in stocking hatchery-reared fish and more interested in depending on the native stock for reproduction. Where stocking is needed, attempts are being made to use native brood stock. Programs are being initiated to study genetic diversity of fish within the state.

Harvest

Humans have been harvesting Wisconsin's aquatic resources for thousands of years, and this harvest has undoubtedly had impacts on biodiversity. There is considerable evidence that Native Americans used nets and spears and even built dams and weirs to harvest fish (Kuhm 1928) and turtles (Adler 1968). European settlers in the mid-1800s began commercially harvesting sturgeon, lake trout, suckers, yellow perch, and other common fish species.

Today, sport, commercial, and subsistence harvest of some aquatic organisms is substantial. Sport harvest activities are primarily directed at game fish species. During 1991, 1.47 million licensed anglers and more than 2-million anglers over-all fished 21.3 million days in Wisconsin. Over 0.5 million anglers were non-residents—second only to Florida in fishing by tourists. Anglers most frequently fish for panfish (bluegill, pumpkinseed, yellow perch, rock bass) followed by walleye and sauger, largemouth and smallmouth bass, northern pike and muskellunge, and crappie (U.S. Dep. Int. / U.S. Dep. Comm. 1993).

Subsistence harvest is practiced by many users to some extent when fish or other sport harvested animals are eaten. However, the only significant subsistence harvest of aquatic organisms currently allowed is a Native American walleye and muskellunge spear fishery. This fishery was reinitiated in 1986 and has been conservatively regulated and extensively monitored (Hansen 1989, Staggs et al. 1990, Hansen et al. 1991, U.S. Dep. Int. 1991).

Commercial overfishing has been directly implicated in the decline of lake sturgeon, certain cisco species, Great Lakes brook trout, and lake trout in Wisconsin waters, although dam construction, habitat losses, and introduction of exotic species were undoubtedly also factors in the decline of these species (Becker 1983).

During this century, regulated sport angling has been the dominant harvest method for most Wisconsin fish. The effects of angling harvest on the most sought-after species are fairly well understood. Non-selective harvest typically increases total mortality and reduces abundance, but anglers generally select for larger fish. Such size-selective harvest can also reduce the relative abundance of older and larger fish, lower the average age of first reproduction, increase growth rates, increase the variability in recruitment (e.g., Spangler et al. 1977, Coble 1988, SPOF 1983), and may alter the genetic composition of a stock (Policansky 1993). Despite these changes, there is little evidence that sport angling alone can collapse sport fish populations. Unrestricted angling since 1946 in Escanaba Lake has not decreased the walleye population (Staggs et al. 1990). Angling has not been cited as a major factor in the extirpation of any fish in Wisconsin (Becker 1983) or extinction of any species in North America (Miller et al. 1989). Careful monitoring of this activity and its impacts, however, remains vital.

Today, managers are increasingly less interested in stocking hatchery-reared fish and more interested in depending on native populations for reproduction. Where stocking is needed, attempts are being made to use native brood stock.

The indirect effects of angling harvest on other species in the aquatic community are less well understood. Nonharvested species are likely to be affected by changes in predation intensity or food availability when game or commercial species are harvested. Species interactions in north-temperate fish communities are complex and often affected by weather or other unpredictable factors (Colby et al. 1987). Under these conditions, demonstrating that changes in nonharvested species are caused by harvest of other species is difficult. Changes in relative abundance of fish

Fishing has been a popular sport in Wisconsin for many years. This photo from the 1930s shows a day's catch of muskellunge from Pine Lake in Vilas County. *Photographer unknown.*

targeted by sport angling or commercial harvest can have measurable impacts on the absolute and relative abundance of plankton species, which in turn can have impacts on nutrient cycling and water quality (e.g., Brooks and Dodson 1965, Shapiro et al. 1975, Kitchell 1992).

Commercial harvest of fish is regulated and information on the harvested stocks suggests that impacts are similar to those caused by sport angling. However, management programs for commercial fisheries on a national and international scale have more frequently than not failed to prevent collapsed stocks (e.g., Ludwig et al. 1993) and in past years commercial fishing here in Wisconsin has contributed to collapsed and extirpated Great Lakes fish (Becker 1983), so these fisheries must be managed conservatively (Peterman and Bradford 1987, Peterman 1990).

There has also been a significant commercial harvest of small fish, aquatic insects, and crayfish for bait sale. It is generally assumed that impacts on the harvested species have been minimal because these species typically have high fecundity or are widely distributed relative to the areas of harvest. However, these fisheries are lightly regulated, and very little information exists on the number of organisms harvested, much less the impact on the aquatic ecosystems.

There is growing evidence that harvest of herptiles is reducing the populations of some species in the United States (Dundee et al. 1992; James Harding, Mich. State Univ., pers. comm.). Changes in status of Wisconsin herptile species caused by harvest are not well known. The recent surge in the herptile pet trade has increased the exploitation of some Wisconsin species and even the state-threatened wood turtle is being smuggled as more states add this species to their protection list, creating a greater demand on protected stocks (James Harding, Mich. State Univ., pers. comm.). Wood turtles are popular turtles for the pet trade in the U.S. and abroad. Snapping turtles have been trapped and hooked for many years in Wisconsin. The pools of the Mississippi have been extensively trapped commercially, resulting in a drastic decline in snapping turtle populations (Vogt 1981). Some evidence indicates that most of the large turtles are gone from the Mississippi and Lower Wisconsin Rivers (Dan Nedrelo, Wis. Dep. Nat. Resour., pers. comm.). Several long-term snapping turtle trappers have indicated that some local snapping turtle populations have been nearly eliminated by harvest pressures. The demand for softshell turtle meat (two species) has increased significantly for European and Japanese markets. Current regulations do not offer any protection for these species and harvest numbers are unknown except for turtles taken by commercial operations as incidental catch. These records indicate that incidental catch of turtles for the last three years has been the highest in 40 years (Marron 1994).

Modernization of wild rice harvesting methods has led to significant overharvest, resulting in lower yield and elimination of some stands (Bernthal et al. 1992, Vennum 1988), although this problem may have been mitigated by current harvest regulation.

Large-Scale Chemical Treatments

Some water bodies which are thought to have undesirable aquatic communities or high numbers of exotics such as carp are chemically treated and restocked with a desired species mix. Chemical treatments usually eliminate all fish and many other aquatic species in a water body including native species and can have at least regional impacts on biodiversity. Becker (1983), in noting the occurrence of a rare bullhead minnow population in the upper Fox River, stated, “the continued poisoning of portions of the Fox River and adjacent waters with antimycin or other fish toxicants, for the purpose of carp removal, may jeopardize or wipe out the only known Great Lakes population of the bullhead minnow.” Chemical treatments of the Rock River system in the 1970s may have eliminated the least darter, a species of special concern from the Maunesha River system (Fago 1992, Becker 1983).

The impacts of chemical treatments are probably confined to the waters treated. Most treated waters are small, but occasionally larger waters such as Beaver Dam Lake, Dodge County (6,542 acres); Delavan Lake, Walworth County (2,072 acres); Horicon Marsh; or the upper Rock River system are treated. Many treated waters were already perturbed by exotics or hyper-eutrophication, and treatments may have improved conditions for native species. On a landscape scale, the relatively small proportion of waters treated make it unlikely that chemical treatments have had a major impact on Wisconsin's biodiversity. However, the lack of a long-term biological monitoring program makes it difficult to determine what effects such treatments have had.

Department Management Priorities

The effects of Department management activities—such as chemical treatments, intensive aquatic habitat alteration, and water level manipulations—on nongame or other nontarget aquatic species is sometimes not considered, given a cursory look, or the nongame species are deemed less desirable than game fish species that have more sport-fishing value. Although these choices are not inherently wrong, they should be made with due consideration to all components of the aquatic ecosystem, particularly on a regional and landscape scale. The need to approach management from an ecosystem management perspective is becoming increasingly evident. Integration of the appropriate programs is essential if we are to respond to the needs of the ecosystem as a whole.

Habitat Improvement Projects

Intensive habitat management practices include: placement of artificial habitat structures such as fish cribs; riprapping or other bank stabilization; construction of channel modification or maintenance structures such as the LUNKER structure (Vetrano 1988); placement of artificially constructed spawning reefs; and spring pond dredging. The impacts of these practices on local biodiversity are unclear. For example, Carline and Brynildson (1977) studied the results of spring pond dredging. Invertebrates usually recolonized dredged areas provided some undisturbed habitat was left. Fish populations sometimes did not change dramatically. Bank stabilization and other channel modification practices were often applied primarily in streams with already disturbed communities with the intent of reestablishing healthy aquatic communities. However, wood turtles typically nest in areas exposed by natural erosion processes along streams (David Evenson, Wis. Dep. Nat. Resour., pers. comm.).

On a statewide scale, it is unlikely that these habitat management practices have had a measurable impact on Wisconsin's biodiversity. Cold-water stream habitat improvement structures have been placed on about 300 miles of Wisconsin's 9,500 miles of trout stream and 33,000 total miles of rivers and streams. The Department has dredged about 60 of the state's 1,700 spring ponds (Carline and Brynildson 1977; Max Johnson, Wis. Dep. Nat. Resour., pers. comm.); some of these were already impacted by agricultural or timber harvest related sedimentation.

Water Level Manipulations

Artificial water level regulation in Wisconsin's 1,550 dammed lakes can have negative impacts on the aquatic system particularly when it deviates substantially from natural patterns. Water levels fluctuate widely in some reservoirs, especially those used for flood control and peaking hydropower operations (Thuemler et al. 1989). Winter drawdowns are frequently done to minimize ice damage to shoreline properties and increase spring runoff storage capacity. These fluctuations have direct impacts when fish or amphibian eggs are stranded and can have indirect impacts when changing water levels favor certain species over others. For example, water level fluctuations apparently favor carp and inhibit reproduction of native northern pike in Petenwell and Castle Rock reservoirs (Jim Kreitlow, Wis. Dep. Nat. Resour., pers. comm.), and low or fluctuating early spring water levels disrupt spawning of northern pike and walleyes (e.g., Johnson 1961, Johnson 1971, McCarraher and Thomas 1972, Holland and Huston 1984, Kallemeyn 1987). Hibernating turtles are susceptible to freezing and desiccation if reservoirs are lowered or drained (Dorff 1990). Heath (1992, 1993*b*, 1993*c*) reported an inverse relationship between the degree of late fall and winter drawdown and turtle population densities in several Wisconsin reservoirs. A species that matures very slowly, like the Blanding's turtle, can be significantly impacted by winter drawdowns, especially since they are already threatened by fragmentation and the loss of habitat (Dorff 1990). Impacts of winter drawdowns on turtles could be minimized by conducting drawdowns prior to October 1st in Wisconsin waters which will allow turtles to seek alternate hibernation sites (Dorff 1990, Heath 1992, 1993*b*, 1993*c*).

In addition, when ice is lowered onto the bottom substrate during a winter drawdown, substrate freezes to the underside of the ice, resulting in scouring and resuspension of sediments (Glenn Miller, Great Lakes Indian Fish and Wildl. Comm., pers. comm.). Organic substrates are both compacted and removed by ice settling on it. During turtle surveys conducted for FERC relicensing on the Chippewa and Peshtigo rivers, it was noted that organic substrates were almost non-existent or compacted in the shallower bays of reservoirs where winter drawdowns were routinely done. Macrophyte plant densities in two reservoirs on the Peshtigo River were significantly less than at other reservoirs on the same river where winter drawdown had not occurred. Correspondingly, turtle populations in these impacted reservoirs were markedly depressed (R. Hay, Wis. Dep. Nat. Resour., unpubl. data).

Water levels are often held higher during summer to facilitate recreational activities and dock access. Higher summer water level may increase littoral habitat for fish (Johnson 1971) or waterfowl, but may increase spawning habitat for carp or affect aquatic macrophytes such as wild rice (Fannucchi et al. 1986). Artificially high water levels in large, shallow lakes can also increase wave damage to littoral areas, increase turbidity, and eliminate macrophytes (e.g., Engel and Nichols 1994). Water levels in large reservoirs are often systematically drawn down to augment summer river flows. Unstable water levels typically result in poor macrophyte development with associated loss of fish and macroinvertebrate habitat, and in extreme cases can impair fish spawning activities. Drawdowns conducted for the purpose of establishing emergent vegetation can increase the opportunity for seeds of exotic nuisance species such as purple loosestrife to germinate and become established (Merendino et al. 1990).

All of the drowned bay mouth estuaries in Lake Superior and many in Lake Michigan are located in Wisconsin. These unique features occur when the mouths of the tributary rivers have formed estuaries enclosed within sand spits formed by along-shore currents, coming and going with changing water levels and storms. These estuaries provide critical habitat for several bird species such as the least tern and piping plover, as well as dune thistle, dwarf lake iris, beach pea, and grass of parnassus.

Estuary Habitat Management

All of the drowned bay mouth estuaries in Lake Superior and many in Lake Michigan are located in Wisconsin. These unique features occur when the mouths of the tributary rivers have formed estuaries enclosed within sand spits formed by along-shore currents, coming and going with changing water levels and storms. These estuaries provide critical habitat for several bird species such as the least tern and piping plover, as well as dune thistle, dwarf lake iris, beach pea, and grass of parnassus.

Many of these estuaries have been degraded by filling and dredging for disposal of industrial wastes, fly ash, taconite tailings, bark and sawdust, and for construction of roads, tank farms, coal storage areas, docks, grain elevators, and small-boat harbors. Developments and alterations are isolating the remaining pockets of estuary (e.g., the separation of St. Louis River estuary from the Allouez Bay estuary), and are causing habitat simplification. Most of Green Bay's Atkinson's Marsh is affected by dredging and filling with fly and bottom ash, dredge spoil, and other wastes behind a bulkhead line. Other estuaries such as at Port Wing, Marinette, and Peshtigo are affected by recreational development, but undisturbed parts also remain. Only a few, such as Flag River and the Kakagon Sloughs, are relatively undisturbed. The Mink River estuary in Door County and some parts of the Kakagon Sloughs have been the focus of protection efforts of The Nature Conservancy.

Lack of Monitoring

The Department has collected a substantial amount of information on the state's aquatic ecosystems over the years. Several statewide surveys of fish distribution have been done (Greene 1935, Becker 1983, Fago 1992). However, these surveys did not provide information on relative abundance of species, and the last survey (in the 1980s) covered only 45% of the state's waters. Other Department or university fish sampling programs cover few waters or a short period of time. The Department's ambient lakes monitoring program collects water quality and limnological information from 50 selected waters but has been in existence for only a decade. The Waters Classification Program, a major statewide survey of physical, limnological, and fishery characteristics of the state's waters, was conducted in the 1960s and 1970s (e.g., Carlson and Andrews 1977). A randomized survey of limnological characteristics of 1,140 lakes was also conducted (Lillie and Mason 1983). The Bureau of Endangered Resources maintains a database of rare aquatic species occurrences, but this is not the result of a systematic inventory. The Bureau of Water Resources Management has also recently initiated a program to collect limnological and macroinvertebrate information as part of their Basin Plan monitoring program. The Department has also conducted many surveys of state waters that were not part of a statewide or regional program.

Numerous surveys of other aquatic organisms have been conducted. Wisconsin's snail populations were surveyed in the 1920s (Baker 1928*a*). Statewide surveys of mussels were conducted in the 1920s and 1970s (Baker 1928*b*, Mathiak 1979), and mussels in the Mississippi River were surveyed in the late 1970s (Ecological Analysts 1981, Theil 1981, Duncan and Thiel 1983). Statewide surveys of crayfish and shrimp were published by Bundy (1882), Creaser (1932), and Hobbs and Jass (1988). Vogt (1981) provided a

Backpack electroshocking equipment allows managers to survey and monitor remote waters. *Photo by Robert Queen.*

summary of collections and descriptions of Wisconsin's amphibians and reptiles, which have been examined in varying degrees of completeness since 1883. The Milwaukee Public Museum maintains a Herpetological Atlas Project which is the current repository for information from these and later surveys. A volunteer frog and toad monitoring survey has been conducted by the Department since 1984 (Mossman and Hine 1984, Mossman and Hine 1985, Mossman and Huff 1990).

Unfortunately, this apparent wealth of survey information falls far short of meeting the critical need for long-term monitoring of Wisconsin's aquatic ecosystems and statewide systematic inventories of aquatic organisms. Data from these surveys are usually not collected in a standardized manner and rarely contain relative abundance information, and surveys are not systematically repeated to track distribution and abundance trends. Information from these surveys is often dispersed among different programs in a variety of computer and paper file storage formats making accessibility difficult. There is a critical need for long-term trend information on the status of aquatic communities using either bioindicator species or community samples. Such trend information will only be obtained by institutionalizing a standardized, statistically valid aquatic ecosystem monitoring program as an integral part of the Department's aquatic management programs. An important basis for such a program would be a systematic inventory of important aquatic organisms across the state's waters.

Bioengineering

Biological engineering to produce faster growing, larger, and more prolific fish species has the potential to alter management goals and objectives from reliance on existing species and strains to designing new species and strains to meet specific management goals and objectives. For instance, it is theoretically possible to engineer more appealing bait fish, new predators, or freshwater fish that continue to grow throughout their lifetimes and attain a weight of several hundred pounds. Past experience with exotic species and predictive management are not accurate or reliable indicators of likely outcomes from adaptive management and biological engineering. However, to the extent that an emphasis and reliance on management diverges from an emphasis on less management with reliance on natural reproduction and a sustainable resource base, conflicts and controversy will result. Judgments on whether the outcomes of these divergent approaches are "good" or "bad" will also depend on the observer's values about resource management.

Beyond these important concerns, there is very little evidence that genetic bioengineering is a viable management option. We barely understand the importance of genetic diversity in native species which have adapted to Wisconsin's waters over millennia. Thus, costly genetic experimentation poses the potential for major disruption of existing aquatic ecosystems.

Recreation

Recreational use of aquatic ecosystems continues to increase. Activities such as boating, canoeing, swimming, camping, and hiking along riparian areas are among Wisconsinites' favored activities (Penaloza 1989, 1991, Wis. Dep. Nat. Resour. 1991). Boats and motors are becoming more numerous and larger (Penaloza 1991). Along with increased demand for these activities comes increasing demand for boat launch ramp, canoe access, beach, marina, campsite, and trail development. Both the recreational use and associated development impact the aquatic ecosystem.

Boating can result in direct impacts to habitat. Outboard motors discharge raw fuel, oils, and other combustion byproducts directly into the water (Jackivicz and Kuzminski 1973, Wall and Wright 1977). Extensive fish kills in the Fox River have been attributed to carbon monoxide discharge from outboard motors (Jim Kempinger, Wis. Dep. Nat. Resour., pers. comm.), though this was an area of exceptionally high use. Heavy boat traffic is known to disturb vegetation and macroinvertebrate production and cause shoreline erosion and sediment resuspension (Lagler et al. 1950, Liddle and Scorgie 1980, Smart et al. 1985). Increased sedimentation is known to have detrimental impacts on fish and other aquatic organisms (e.g., Berkman and Rabeni 1987, Ritchie 1972, Ellis 1936). Heavy boat use is often blamed for turbidity which can also adversely affect aquatic organisms (e.g., Van Oosten 1945, Gardner 1981, Breitburg 1988, Robel 1961, Newcombe and MacDonald 1991, Lloyd et al. 1987,), but there is mixed evidence for this relationship (Lagler et al. 1950, Moss 1977, Liddle and Scorgie 1980, Yousef et al. 1980). Boat traffic also disturbs waterfowl and other aquatic wildlife. (See review by York 1994.) Movement of boats among waters can transport propagules of exotic species such as Eurasian water milfoil and zebra mussels.

Heavy use of riparian areas can result in bank erosion, vegetative destruction, littering, and demands for increased camping and access site development (e.g., Manning 1979). Recent interest in marina construction in the Minnesota-Wisconsin boundary waters of the Mississippi and St. Croix rivers will add to congestion on what is already one of the most crowded and congested areas in the country for boating (Tom Watkins, Wis. Dep. Nat. Resour., pers. comm.). There is some evidence that pollution levels are higher near marinas (Mack and D'Itri 1973). Habitat will also be lost due to dredging and riprapping for development of facilities to support recreational activities such as marinas, condominiums, boat launches, and parks.

While perhaps not of great historical impact on Wisconsin's aquatic ecosystems, the current effects of concentrated boating and other water recreational activities are documented. Given the dramatic increase in the levels of these activities in recent years, resulting changes in the aquatic communities must be monitored carefully.

Recreational boating is a favorite activity in Wisconsin. Boats and motors are becoming more numerous and larger, placing increased pressure on aquatic systems. *Photo by Robert Queen.*

Present Status

Quantitative analyses of the present status of aquatic ecosystems in Wisconsin require a statewide database of systematically collected biological samples. Such a database exists only for fish (Greene 1935, Becker 1983, Fago 1992). Other taxa including aquatic macrophytes, phytoplankton, zooplankton, benthic invertebrates, crayfish, amphibians, and some reptile, bird, and mammal species are clearly dependent on aquatic systems, but there is far less systematic data on their distribution and abundance. This section will use fish distribution data to quantitatively assess present aquatic ecosystem health across the state.

The status of the aquatic communities can be successfully indexed by fish communities (Karr 1981, Fausch et al. 1990, Lyons 1992). Extensive fish surveys of Wisconsin waters by Greene (1935), Becker

Aquatic macrophytes are an important component of aquatic biodiversity. Systematic data on their distribution and abundance is needed. *Photo by Dorothy Cassoday.*

(1983) and Fago (1992) provide a quantitative basis for discussion of the current status of Wisconsin's aquatic communities. Use of indicators such as presence of fish species intolerant to environmental degradation (Lyons 1992), species richness, history of extirpations, current status of threatened species, and status of natural reproduction of top-level predators show trends in aquatic ecosystem health.

Great Lakes

The shoreline of parts of the Great Lakes has been modified by urban, industrial, and second-home development, especially in urban areas such as Duluth-Superior, Green Bay, Milwaukee and along the Lake Michigan shore near the Illinois state line. Shoreline protection efforts such as groins, jetties, cribs, dredging, and navigation channel entries have interfered with long shore movement of littoral drift. Erosion and scouring of the down-drift side of these structures is occurring. Other shoreline changes such as riprap, sheet pile walls, gabions, or concrete retaining walls are used in an attempt to stabilize the shoreline. They retard the natural process of beach formation and destroy unique beach and bank plant communities. Alteration of water levels and natural fluctuations has affected dune and coastal marsh systems by interrupting nutrient and organic matter flushing (The Nature Conservancy 1994). Changing water level fluctuation cycles is leading to the simplification of coastal marshes by eliminating species that require drawdowns at certain times to allow germination (Keddy and Reznicek 1986).

Contaminants, particularly PCBs, are commonly found in many Lake Michigan and Green Bay fish and waterfowl at levels which require consumption advisories. Contaminants in the Great Lakes sediments and waters have been passed along through the food chain, resulting in contamination of invertebrates, fish, wildlife, and humans. Contaminants remain in the bottom sediments, and fish in remote parts of Lake Superior have mercury and PCB in their tissues, indicating contamination may still be occurring due to atmospheric deposition. Monitoring indicates that contaminant levels have been declining in Lake Michigan fish since the 1970s (e.g., Staggs 1987) though rates of decline have slowed because of internal cycling and continued atmospheric deposition (Arimoto 1989). Monitoring of Lake Superior fish shows lower contaminant levels.

The Great Lakes aquatic community has also been affected by humans. The Great Lakes fish community is a good example. The effects of lamprey predation, water quality degradation, invasion of exotics, and overfishing have combined to radically alter the fishery. Some species of cisco have been extirpated in Lake Michigan. Strains of other species, such as lake trout and brook trout, have been eliminated or greatly reduced. Introductions and invasions of non-native fish species, such as rainbow and brown trout, Pacific salmon, smelt, and alewife have changed the species composition of the fishery. However, the introduction of the salmon resulted in the decline of alewives and a comeback in native perch, sculpins, and coregonids (Stewart et al. 1981, Eck and Brown 1985, Jude and Tesar 1985, Wells and Hatch 1985). Other species, such as perch, undergo periods of intensive harvest. Undoubtedly predator/prey relationships have been affected by these changes in the fish community.

The status of the fish communities in Lake Michigan is best described as disturbed and unstable (Wells and McLain 1973). Reproduction of trout and salmon is negligible, and populations are primarily supported by stocking. Sea lamprey predation, angler harvest (Clark and Huang 1985), and overstocking (Stewart et al. 1981) all affect fish populations. Reproduction and populations of native deepwater sculpins and bloaters are at recent highs, while non-native alewive populations are extremely variable but are at recent lows (Jude and Tesar 1985, Wells and Hatch 1985). Populations of lake and round whitefish seem abundant and relatively stable (Wells and McLain 1973). Of the seven cisco species once found in Lake Michigan, only the cisco and bloater remain in numbers sufficient to preserve the population. Three cisco species—shortnose, blackfin and deepwater—are likely extinct (Becker 1983). Two other cisco species—shortjaw and kiyi—while likely extirpated in Lake Michigan are still relatively abundant in Lake Superior. Excessive commercial harvest and competition from alewives are cited as primary causes of cisco population declines.

Among Lake Michigan warm-water species, reproduction and populations of northern pike are currently limited. Walleye and yellow perch reproduction is now significant in Green Bay, but populations are still experiencing large fluctuations. Yellow perch are well-established in other areas such as Milwaukee harbor, but walleye populations are negligible. Lake sturgeon populations are probably low but the current level of reproduction of this long-lived species is unknown. Reproduction of other warm-water species appears adequate to maintain the stocks.

In Lake Superior, fish communities, although heavily exploited, are more stable (e.g., Lawrie and Rahrer 1973). There is significant natural reproduction of most trout and salmon species, but angler and commercial harvest and sea lamprey predation have kept adult populations at a relatively modest level. Reproduction and populations of other cold-water species is adequate, but overall productivity in Lake Superior is low so populations are often modest by Lake Michigan standards and cannot support as large a predator population. Only four cisco species—cisco, bloater, shortjaw, and kiyi—were originally present in Lake Superior and all are still present in sufficient numbers to maintain populations. Lake Superior is also home to the only known population of pygmy whitefish east of the Rockies. It is abundant and relatively stable (Becker 1983). With some local exceptions, reproduction and populations of Lake Superior warm-water species are adequate to maintain the stocks.

Fish communities—specifically the abundance of lake trout—can be used as indicators of the status of the entire aquatic community in the Great Lakes (Ryder and Edwards 1985, Marshall et al. 1987). Based on this assumption, Lake Michigan has been dramatically affected by habitat simplification— primarily dredging, wetland filling and water quality declines in estuarine areas, introduction of exotic species, excessive harvest of commercially desirable top predators, and pollution.

The uncertain status of lake sturgeon reproduction indicates fragmentation of the lake ecosystem, as lake populations were cut off from historical spawning areas by dam construction. Lake Michigan, however, shows some signs of recovery: declining numbers of exotic species, improving reproduction of some native species, and declining contaminant burdens (e.g., Wells and McLain 1973).

Conversely, Lake Superior shows few signs of either habitat simplification or fragmentation. The aquatic community has primarily been affected by human management activities, including excessive harvest of commercially desirable species, stocking of domesticated strains of lake trout, and introduction of exotic species (Lawrie and Rahrer 1973). Localized habitat degradation in the urban areas of Duluth-Superior may also be occurring but does not appear to be affecting Lake Superior biodiversity on a lake-wide scale.

Inland Lakes

Fish species intolerant of poor water quality and environmental degradation (Lyons 1992) such as smallmouth bass, rock bass, Iowa darter, blacknose shiner, and spottail shiner were found at 56% of the 1,644 sampled lake stations (Table 19). Species richness averaged 7.2 species per station with a range of one to 23 species (Table 20).

There are currently no federally threatened or endangered fish species in Wisconsin lakes, although six species are under consideration for federal listing. No known extinct species were endemic to Wisconsin lakes (Becker 1983). Several species are thought to have been extirpated

Table 19

Percent of stations with tolerant and intolerant fish species in Wisconsin lakes and rivers, classified by ecoregion as defined by Omernik and Gallant (1988), based on nearest county boundary. (Data source: Wisconsin Fish Distribution Study Master Fish File.)

Ecoregion	Total Stations	Stations with Intolerant Species*	Percent with Intolerant Species*	Stations with Tolerant Species*	Percent with Tolerant Species*
Lakes					
Driftless Area (DRFT)	22	11	50	17	77
N. C. Hardwood Forest (NCHF)	355	203	57	266	75
N. Lakes and Forest (NOLF)	660	424	64	511	77
S.E. Wis. Till Plains (SETP)	607	276	45	471	78
Statewide	1,644	914	56	1,265	77
Streams					
Driftless Area (DRFT)	1,586	886	56	1,466	92
N. C. Hardwood Forest (NCHF)	1,079	850	79	977	91
N. Lakes and Forest (NOLF)	1,317	1,029	78	1,149	87
S.E. Wis. Till Plains (SETP)	1,433	662	46	1,376	96
Statewide	5,415	3,427	63	4,968	92
Rivers					
Driftless Area (DRFT)	331	289	87	245	74
N. C. Hardwood Forest (NCHF)	75	46	61	55	73
N. Lakes and Forest (NOLF)	68	59	87	39	57
S.E. Wis. Till Plains (SETP)	26	19	73	20	77
Statewide	500	413	83	359	72

*Tolerance and intolerance to environmental degradation as defined by Lyons (1992).

from Wisconsin waters, including ghost shiner, ironcolor shiner, and creek chubsucker, but these were probably not common in lakes. Wisconsin lists nine species of endangered fish and 11 fish species as threatened, although most of these species are on the edge of their range in Wisconsin and were never common in lakes.

Differences in fish communities among ecoregions suggest that biodiversity in SETP lakes has been more heavily influenced by human activities compared with NOLF and NCHF lakes. Comparisons

Table 20

Analysis of fish species richness in Wisconsin lakes and rivers, classified by ecoregion as defined by Omernik and Gallant (1988), based on nearest county boundary. (Data source: Wisconsin Fish Distribution Study Master Fish File.)

Ecoregion	No. Fish Species, by Water Type							
	Lake		River		Stream		All	
	Mean	STD	Mean	STD	Mean	STD	Mean	STD
Driftless Area (DRFT)	8.00	4.15	15.19	7.36	9.08	5.43	10.11	6.23
N. C. Hardwood Forest (NCHF)	7.41	4.02	11.53	7.99	10.35	6.30	9.72	6.08
Lakes and Forest (NOLF)	7.02	3.52	11.99	5.92	8.10	4.59	7.88	4.42
S. E. Wis. Till Plains (SETP)	7.19	4.29	11.42	8.76	9.88	5.76	9.11	5.56
All	7.18	3.94	14.01	7.52	9.31	5.58	9.16	5.64

with DRFT lakes are difficult because few lakes exist or were sampled in that ecoregion. Species regarded as intolerant of environmental degradation were present at only 45% of sampled SETP stations (Table 19). Five state-threatened and one state-endangered species were found in SETP lakes including pugnose shiner, redfin shiner, river redhorse, starhead topminnow, striped shiner, and longear sunfish.

In contrast, fish communities in NOLF and NCHF lakes showed less evidence of biodiversity impacts. Species intolerant of environmental degradation were present at 64% of sampled NOLF stations and 57% of NCHF stations. Tolerant species such as carp and green sunfish are generally uncommon (see Table 13). Intolerant species such as the small-mouth bass, rock bass, and Iowa darter are more common. Only the state threatened pugnose shiner, redfin shiner, Ozark minnow, and longear sunfish were found in any NOLF or NCHF lakes, and it is unlikely that any species were extirpated from lakes in these regions. One species thought to be extirpated from SETP waters (Becker 1983), the black redhorse, was recently found in a NCHF reservoir (Fago and Hauber 1993).

The current status of NOLF and NCHF lakes as indexed by fish communities is healthy and stable. Reproduction and abundance of top level predators is generally adequate (Staggs et al. 1990, U.S. Dep. Int. 1991), and a large proportion of sampled stations have species that are intolerant to environmental degradation. Species richness is less than that of southern Wisconsin lakes, but waters in more northerly latitudes are often species poor to begin with (Lyons 1992).

Localized impacts such as dam construction in NCHF lakes are not readily apparent in this regional analysis but are known to be important in specific waters. Water level fluctuations and high nutrient loading are thought to have resulted in poor water quality and high carp populations in the region's two largest reservoirs, Castle Rock and Petenwell (Jim Kreitlow, Wis. Dep. Nat. Resour., pers. comm.).

Piscivorous birds have been impacted by water quality problems in NOLF lakes. Common loons rarely nest on lakes with low pH and elevated mercury levels and suffer higher reproductive mortality in these locations (Meyer 1994).

With regard to aquatic vegetation, wild rice areas in northern Wisconsin have been lost to flooding caused by dams (Vennum 1988).

Streams

No federally threatened or endangered fish species are found in Wisconsin streams, but six species are currently under consideration for federal listing. At least three species, ghost shiner, ironcolor shiner and creek chubsucker, have been extirpated from state streams. The nine state-endangered and 11 state-threatened species are found in state streams. Most are on the edge of their distribution, but species such as the river redhorse, pallid shiner, crystal darter, and gilt darter are declining across their ranges. Wisconsin has some of the best populations of greater redhorse and pugnose shiners across their ranges (Lee et al. 1980) even though they are listed as threatened in this state's streams.

Species intolerant of environmental degradation, such as brook trout, small-mouth bass, and rock bass (Lyons 1992), were found at 63% of the 5,415 stations sampled statewide (Table 19). Species richness is higher in streams than lakes, averaging 9.3 statewide and with a range of one to 40 species per station (Table 20).

In comparison with NOLF and NLHF streams, patterns of fish distribution suggest that some streams in the SETP and DRFT ecoregions have diminished biological integrity. Intolerant species were found at only 46% and 56%, respectively, of sampled stations. While many species shifts are due to underlying habitat differences such as larger streams and warmer temperatures, the increased abundance of tolerant species such as carp, green sunfish, bluntnose and fathead minnows, and yellow bullhead provide evidence for environmental perturbation (Table 15).

NOLF	Northern Lakes and Forest
NCHF	North Central Hardwood Forest
DRFT	Driftless Area
SETP	Southeast Wisconsin Till Plains

Other studies suggest that smallmouth bass populations in DRFT streams have experienced major declines during the last three decades (Forbes 1985, Mason et al. 1991).

Two state-endangered and eight state-threatened fish species were found at SETP stations; one state-endangered and nine state-threatened fish species were found at DFRT stations; no state-threatened fish species were found at NCHF stations; and three state-threatened fish species were found at NOLF stations.

Large Rivers

Species regarded as intolerant to environmental degradation (Lyons 1992) occurred at 83% of sampled stations. Rivers exhibit the highest species richness of all the aquatic communities, averaging 14 species with a range of one to 40 species per station.

No federally threatened or endangered fish species are found in Wisconsin rivers, but six species are currently under consideration for federal listing. At least three species, ghost shiner, ironcolor shiner and creek chubsucker, have been extirpated from state streams and rivers. The nine state-endangered fish species and many of the 11 state-threatened fish species currently inhabit state rivers. Most are on the edge of their distribution, but species such as the paddlefish, blue sucker, river redhorse, pallid shiner, crystal darter, and gilt darter are declining across their ranges. Wisconsin has some of the best populations of greater redhorse across their ranges (Lee et al. 1980) even though they are listed as threatened in this state's rivers.

Differences in river fish communities between ecoregions were not pronounced. Average species richness is higher in the DRFT ecoregion, but this is probably because the largest rivers, the Mississippi River and the lower Wisconsin River, are located here. Species intolerant to environmental degradation are found at a large percentage of sampling sites in all ecoregions (Table 17). Intolerant species were found at only 61% of NCHF river stations perhaps reflecting impacts of damming and paper mill pollution on the Wisconsin and Chippewa rivers.

Several state-threatened fish species are common in NOLF, NCHF, and DRFT rivers. Only three state-threatened species—gilt darter, river redhorse, and blue sucker—have been found in NOLF rivers, but the gilt darter and river redhorse were found at one third of the sampled stations suggesting they are not threatened in the NOLF ecoregion. Seven state-threatened fish species were found in NCHF rivers. DRFT rivers have nine state-threatened and one state-endangered fish species. The four state-threatened and one state-endangered fish species found in SETP rivers but are not common in that region's rivers.

NOLF rivers contain the lowest percentage of intolerant species among the four ecoregions suggesting there has been environmental degradation in the ecoregion. However, there is evidence that NOLF fish communities are still relatively healthy. River redhorse, a state-threatened species known to be affected by dam construction, was present at 30% of sampled stations. Also, the gilt darter, a state-threatened species intolerant of environmental degradation, was found at 32% of sampled stations. Most top predator species exhibit self-sustaining populations.

These analyses show that some stations have degraded fish communities, while fish communities at many stations remain intact. This finding is consistent with the observation that dam construction is a major environmental impact on Wisconsin's rivers since the most significant effects of a dam would be localized in areas near the dam.

Projected Status

Some taxa dependent on aquatic systems in Wisconsin face a difficult future. The abundance and zoogeographical distribution of Wisconsin's river mussels have been dramatically altered. Three species have been extirpated (scaleshell, fat pocketbook and pyramid pigtoe), two have only remnant populations (ebony shell and elephant ear), and two are on the federal endangered species list (winged mapleleaf, higgins eye). If the invading zebra mussel affects native mussel species as severely as predicted, up to half of the states stream and river mussel species will be threatened or endangered.

Other taxa are in better condition. Although the abundance of many fish species has been greatly altered, very few fish species have been extirpated in Wisconsin. Of the fish species locally extirpated, some have later been found again, although in very low numbers (e.g., black redhorse and skipjack herring), and most extirpations involved species on the edge of their range. There are no federally endangered or threatened fish species in Wisconsin, although the lake sturgeon, blue sucker and paddlefish are among the candidates for listing. It appears most extirpations have been caused by habitat destruction, primarily associated with agriculture and dams. In general, most native fish species are self-sustaining, especially in Lake Superior and the northern ecoregions. Even the heavily developed agricultural areas and densely populated areas of southeastern Wisconsin still support self-sustaining fish populations and good species diversity in some waters.

The relative abundance of currently healthy aquatic communities in many inland waters is an excellent indicator for the future. Attention can be focused on identification and restoration of specific degraded habitats and on protecting and restoring species whose numbers are in local decline. Existing aquatic communities provide a source for recolonization of native species and a model for restoration efforts. Past restoration successes, such as those on the Wisconsin and lower Fox Rivers, provide clear evidence that such efforts will work. Further progress and additional successes can be expected as the Department works cooperatively with industry to install the latest pollution abatement equipment and

The abundance and distribution of Wisconsin's river mussels have been dramatically altered. The winged mapleleaf, shown here, is on the state and federal endangered species lists. *Photo by William Smith.*

develop pollution prevention technology. Many priority watershed plans already recommend removal of dams to improve water quality. Dam removal may be an effective option for restoration of riverine ecosystems.

The most cost-effective management strategy is protection of existing healthy, self-sustaining aquatic ecosystems. However, pressure remains to develop and destroy riparian habitat, modify land use patterns in watersheds, intensify agriculture, divert water for irrigation and industrial uses, and provide more harvest opportunities for sport anglers and subsistence users. Government agencies and users will have to establish and maintain strong partnerships if long-term sustainability of aquatic ecosystems is to be maintained.

The most cost-effective management strategy is protection of existing healthy, self-sustaining aquatic ecosystems.

The accidental or intentional introduction of exotics has already been implicated in major changes in native biodiversity. Past invaders, including carp, Eurasian milfoil, and purple loosestrife are notoriously hard to control and eradicate. The state has invested heavily in control, education, and monitoring, but efforts to eliminate targeted exotics have shown poor results. Undoubtedly, new exotic species will continue to be introduced, and the potential threats to the aquatic community will increase.

Healthy, diverse aquatic communities are present in many inland waters. *Photo by Dean Tvedt.*

Two other possible threats to the aquatic community present unknown dangers—the potential effects of climate change and the effects of acid deposition (Bergquist 1991). Assessing the likelihood of either of these threats is dependent on the development of accurate predictive models. Global climate change could change the numbers and distribution of aquatic species in Wisconsin. However, the climate change threat is only in the early stages of monitoring and model development (U.S. Dep. Energy 1990).

Socio-Economic Issues

The aquatic community has a faithful and dedicated following of avid anglers, recreationists, and other user groups. Conflicts can occur as more people try to use a limited resource for purposes that are not easily compatible, such as water-skiing and fishing. In some cases, there is a strong feeling of "my lake," "my river," "my trout stream," and "my spot," particularly among local residents and riparian owners, which may place them in conflict with other statewide users.

Recreational fishing has a significant impact on aquatic communities. In Wisconsin, fishing is the sixth most popular outdoor activity among all adults (26% of all adults) (Wis. Dep. Nat. Resour. 1991). In some areas of the country, fishing is now so intense that previously underexploited recreational fisheries are now thought to be approaching overexploitation, although this concern is not well documented in Wisconsin.

The popularity of fishing has come at a price. The state's fishing public, which is among the five largest in the nation (U.S. Dep. Int./U.S. Dep. Comm. 1993), demands an intensive fishery management effort. Resort owners want more large predators such as walleye, muskellunge, and northern pike, while trout anglers want more trout. More access is required to meet the demands of more people who own more boats with bigger motors and who purchase more licenses and pay higher fees. More demands require stretching the resources of the aquatic community to provide for more return, much as a farmer may try to increase yield from a corn field.

The short-term expectations of resort owners and other interests lead to increased pressure for management actions, such as fish-stocking, habitat manipulation, and single species management, rather than practiced restraint and reliance on natural recruitment to replenish a fishery. As the pressure for providing short-term solutions increases, the interest in the long-term health and diversity of the aquatic community could diminish.

There is heavy economic pressure to continue developing shoreline property. Lake homes continue to be in high demand. Some counties, such as Vilas and Oneida, are growing rapidly due to the demand of retirees for lake and waterfront homes. Former resorts are being converted to condominiums. This demand now threatens the smaller, more isolated, shallow lakes that were not developed earlier because they were "less desirable."

The agriculture industry is an extremely important component of Wisconsin's economy, and its impacts on aquatic ecosystems in Wisconsin are well documented. The Priority Watershed program along with stream bank protection acquisitions and easements under the Stewardship Program are the main management activities targeted at reducing this large source of pollutants and erosion, but both are largely voluntary programs.

An evaluation of the socio-economic implications of managing Wisconsin's aquatic ecosystems reveals many of the same problems that mark similar analyses of natural resource issues. Documentation of the value of development and industry needs is straightforward and readily available. Hydropower will generate electricity worth a certain amount. Lakeshore development yields a certain amount of property taxes for local government. Industries using aquatic resources employ a certain number of people and contribute a certain amount of tax revenues to local governments. Family farms employ a certain number of people and generate a certain level of expenditures in the rural communities. However, documentation of the value of the aquatic resource degraded or lost is less certain and often involves hard-to-quantify intrinsic values. What is the value of the nongame species killed by a pollution discharge? What is the value to the local economy when tourism declines because of poor fishing, increased pollution, or loss of scenic beauty? What is it worth to be sure future generations will be able to enjoy clean water, good fishing, and scenic recreational areas? A major challenge to maintaining the long-term sustainability of Wisconsin's aquatic ecosystems will be to develop adequate valuations of the importance and uses of these ecosystems, and to ensure that society and future generations are not paying for short-term benefits that limit future options. However, according to Clark (1991), "the political realities are that exploiters of large resource stocks have every incentive to impose major external costs on the public at large, and these externalized costs add up to nonsustainability."

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Potential for Community Restoration

Aquatic systems can probably recover more quickly than terrestrial systems from the impacts of fragmentation or simplification if the causes are corrected. In rivers and streams, sediments and contaminants are flushed downstream, hydrologic processes will restore channel morphology, riparian areas will revegetate, and aquatic organisms will return provided there are no barriers to recolonization from unaffected areas (Detenbeck et al. 1992). Macroinvertebrates, for example, generally recover very quickly (months to just a few years) from most kinds of disturbances (Niemi et al. 1990) and colonize new habitats very rapidly (e.g., Williams and Hynes 1977, Doeg et al. 1989). Narf (1985) found aquatic insect colonization of available habitat in a relocated stream segment in northern Wisconsin was complete after 5.5 years. Many other aquatic organisms are mobile and fecund, allowing rapid recolonization and repopulation of affected areas.

Restoration of lakes may take longer or require more directed management actions. Lakes that have been exposed to contamination or excessive nutrient loading usually take longer to recover than rivers and streams because flushing rates are much longer and nutrients and contaminants are continually recycled from sediments. Morphology in lakes is not shaped by strong currents, so restoration of altered habitat may take extremely long periods. Revegetation of riparian areas would be similar to moving water systems, but replacement of woody debris habitat would be slower since it is not being actively transported from upstream areas. Lakes also tend to be more isolated from other

Remote lakes such as Gobler Lake in Oneida County offer valuable insight into restoring aquatic communities. This lake is located within a State Natural Area. *Photo by William Tans.*

lakes, which would slow recolonization by aquatic organisms.

There are few if any undisturbed aquatic ecosystems in Wisconsin to use as templates for restoration efforts. However, there are many systems that, while disturbed, still maintain a healthy complement of native species. These systems must serve as models for restoration and as sources of genetic stock for recolonization efforts. When restoration of pre-settlement aquatic ecosystems is a desirable goal, studies of undisturbed systems in other regions or use of paleolimnology techniques may be needed to establish realistic goals. Determining restoration objectives will not always be straightforward. Historically and currently, recreational and commercial fishing demands guide management efforts and some components of the aquatic community may consequently be considered less important in restoration projects. Careful consideration of the costs of different management activities and a balancing of management objectives across various scales must be part of any restoration plan.

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A basic barrier to both restoration and maintenance of sustainable aquatic ecosystems is the lack of meaningful ability to regulate habitat destruction. The Department has only minimal authority to regulate environmental impacts from agriculture. On paper the Department should be able to minimize destruction of riparian habitat areas, but in practice such destruction continues. Land use practices in nonriparian areas of a watershed can have major impacts on downstream aquatic systems, but zoning and other land use regulations rarely consider aquatic impacts.

The successes of point-source water pollution regulation should be a model for regulation of nonpoint pollution and riparian development. The substantial investments made by both governmental agencies and state industries in water quality improvements are showing results and should serve as a model for other restoration efforts. For example, water quality in the Wisconsin and Fox rivers has been considerably improved and the aquatic resource, most notably fish species, has improved as well.

However, many waters in Wisconsin still need attention. The atmospheric transport of pollutants across the continent and throughout the region results in the deposition of combustion byproducts, sulfur and nitrous oxides, mercury, and PCB's from industries in other states or nations to Wisconsin's waters. The results, such as acid deposition, have been implicated in raising the level of mercury contamination in fish from waters that are not exposed to other sources of pollution (Lathrop et al. 1990). Contaminant advisories still remain for some species of fish, such as carp and white bass. In addition, the allowable residue in fish flesh continues to be lowered, reflecting the improving technology of contaminant detection and the interests of Americans in maintaining a healthful lifestyle. Despite some declines in the levels of PCB's in Great Lakes fish (Staggs 1987), the problem of toxics from some materials, such as dioxins and PCB's, will continue for a long time due to their persistence and cycling in the environment, which may be on the order of several hundred years. Some in-place pollutants have been covered by recent deposition of cleaner sediments, but these overlaying layers can be removed during dredging or scouring during floods. Additional sources of pollutants may occur as a result of groundwater inputs from the thousands of abandoned landfills and leaking underground storage tanks.

State industries have already made substantial investments in pollution abatement equipment, which has reduced the level of pollutants being added to aquatic systems. However, remedial actions to clean up past pollution will be technically difficult and very costly. There is increasing recognition among government agencies and state industries that development of pollution prevention technology is a more cost-effective option than paying for later clean-up of pollutants.

There are few selective controls for exotic species and none are cost-effective on a large scale. One method to control exotic fish in small waters is to eradicate the entire fish community and start over. More often than not, the inconvenience of an exotic fish species is tolerated because of the costs, controversy, and difficulty of completely removing it along with most of the rest of the aquatic community. Maintaining a large predator biomass may be helpful over a long period (Stewart et al. 1981), but extirpation of local forage fish species or shifts in species composition of zooplankton and phytoplankton may occur. Herbicides can be applied to small infestations of certain plants, but large scale control is expensive and damaging to related native species. No control methods exist for exotic bivalves and zooplankton. There is evidence that healthy native aquatic ecosystems are more resistant to invasions of exotics (Baltz and Moyle 1993).

Concerns about the effect of climate change on the aquatic community are starting to surface. Regier et al. (1990) describe three levels of connections between climate change and fish. First, there is a direct connection between local climate and local assemblages of fish. Second, there are indirect linkages between climate, hydrology, and the biotic system. Finally, there is the human and cultural response to these changes.

Weather extremes of the past decade and the possibility of global climate change make it difficult to predict any resulting changes in the aquatic community. The past decade has been marked by unprecedented droughts preceded by periods of extreme wetness. The cold-water resources of the northeastern and southwestern parts of the state have been affected by past droughts, and the Great Lakes littoral areas and shorelines have been affected by high water and resulting shoreline erosion and wave damage. The recent variations in climate fall within the bounds of predictions from the atmospheric general circulation model that predicts climate change.

Effects of climate change could include decreases in winter ice cover on the Great Lakes (Sanderson 1987); the development of a permanent thermocline in the deeper parts of Lake Michigan overlain by a seasonal thermocline such as occurs in most of the world's oceans (McCormick 1990); hypolimnetic anoxia (Schertzer and Sawchuk 1990); increased bacterial activity in the hypolimnion and sediments (Blumberg and Di Toro 1990); changes in habitat for Great Lakes cold-, cool-, and warm-water fish (Magnuson et al. 1990); changes in fish growth rates (Hill and Magnuson 1990); reduced stream habitat for brook trout (Meisner 1990); expansion of the range of the exotic white perch in the Great Lakes (Johnson and Evans 1990); extension of the northernmost ranges of yellow perch and smallmouth bass (Shuter and Post 1990); possible local extinctions of southern fish populations and northward invasion of southern fish populations (Tonn 1990); and the invasion of species adapted to warm conditions concurrent with local extinctions of some cold-water species (Mandrak 1989).

Most of the consequences of today's aquatic habitat problems are the result of changes brought about by agriculture, forestry, and urban development practices several decades ago. Some positive trends are now on the horizon, such as the Conservation Reserve Program provisions of the 1985 Food Security Act. In 1988, Wisconsin adopted Water Quality Standards for a broad range of contaminants. The 1990 Farm Bill strengthened the requirements for environmental protection and attempted to lessen the water quality impacts of agriculture (Pajak 1991). However, later versions could change these gains. Additionally, the Department's Stewardship and Forestry Best Management Practice Programs have a substantial component devoted to water resources protection. Increased interest in wetland protection and sustainable agriculture may lead to lower chemical inputs and less erosion, while changes in manufacturing methods and waste treatment portend possible decreases in wastewater discharges.

Possible Actions

The following possible actions are consistent with ecosystem management, but require more analysis and discussion. How priorities are set within this list will be based on ecoregion goals, staff workload, fiscal resources, public input and support, and legal authority. We will work with our customers and clients to set priorities and bring recommendations to the Natural Resources Board for consideration beginning in the 1995-97 biennium.

1. Apply the principles of ecosystem management to the many kinds of aquatic communities and their associated species. Put less emphasis on single species management and more on communities and ecosystems. One benefit will be the cost-effectiveness of managing for native, naturally reproducing species assemblages and up-front protection of habitat.

2. Use a landscape scale approach to set watershed or ecoregion-based goals for the protection and management of lake systems. This will involve work with many partners, public and private, to apply the ecological, socio-economic, and institutional aspects of ecosystem management to a comprehensive view of our lake resources and the conservation of statewide biological diversity.

3. Recognize the importance of protecting certain unique types of aquatic communities (e.g., historic wild rice stands), undisturbed aquatic communities (e.g., wilderness lakes), and long-lived native species (e.g., 100 year-old-ebony shell mussels, 75-year-old snapping turtles, and 120-year-old lake sturgeons). These are often are economically valuable, add stability to ecosystems, are a reservoir for genetic diversity, and have tremendous scientific value for understanding the processes that affect managed and harvested systems. The concept of old growth, usually applied to forest communities, may help us manage and value populations of long-lived aquatic species and species assemblages.

4. Manage rivers as ecological continuums from headwater to mouth, taking into account adjacent floodplain and terrestrial habitats. Recognize the role of floods in maintaining the integrity of river ecosystems. To do this, we will work with many public and private partners to develop ecoregion or watershed goals and objectives based on ecosystem management principles. This will include reaching a consensus on the desired outcomes after considering a full range of management opportunities (e.g., nonpoint source control, recreational use, industrial activity, aquatic community restoration, and enhancement of fisheries and aquatic life).

   a. Emphasize the protection of the last large river systems without dams. These include the Lower Chippewa

River, Lower Black River, and the Namekagon/St. Croix Rivers.

b. Where appropriate, identify opportunities for upstream and downstream fish passage at existing and proposed dams.

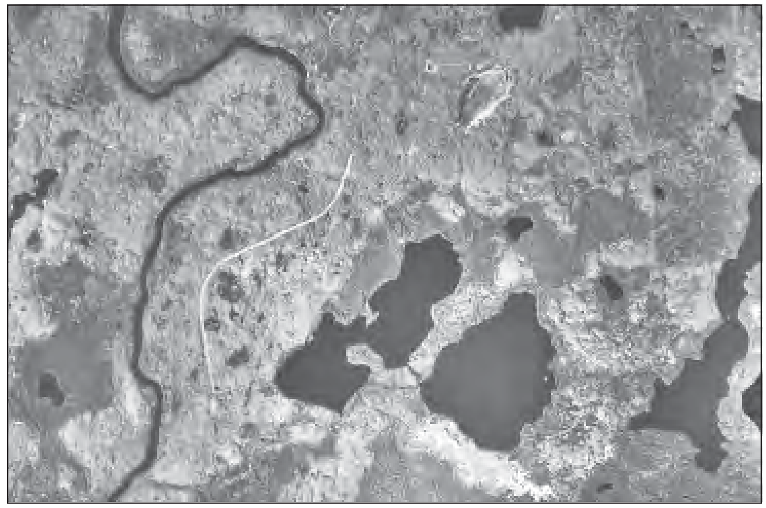
c. Where flows are adversely affected by dams, seek to establish adequate minimum flows to protect recreation, water quality, and fish and aquatic life. Prepare drought contingency plans for rivers where there are consumptive uses or conflicting uses.

d. Document the cost and benefit of dam removal for selected restoration projects, and use the analysis within the ecosystem management decision model to recommend appropriate action.

e. Encourage the preparation of hydroelectric flow models based on entire river systems.

f. Examine the practice of removing natural woody debris from stream beds for channel maintenance. If needed, prepare guidelines to protect instream habitat structure.

5. Manage riparian and shoreline forests using ecosystem management principles. Allow floodplains to develop mature forests to minimize the impacts of flooding and to maintain channel geomorphology. Use Wisconsin's Forestry Best Management Practices guidelines, which require a buffer area of at least 100 feet along shorelines, to plan timber harvest. These buffers are sources of fallen woody debris to maintain instream habitat structure, and they provide shade to control stream temperature. They also protect banks and ground vegetation from damage caused by heavy equipment.



Aerial photographs and satellite imagery are among the tools that help managers take a landscape scale view of aquatic systems.

[Top] *Photo by National Aerial Photography Program.* **[Bottom]** *Photo by Univ. of Wisconsin-Madison Environmental Remote Sensing Center*

6. Develop programs, regulations, and guidelines that effectively protect riparian and shoreline habitats. This will include work with local governments and private groups to develop a common understanding of the impacts and long-term costs of poorly planned riparian and shoreline development and to provide the support needed to design and implement long-range plans that provide adequate protection. We will need to promote a combination of approaches that include:

   - zoning practices, such as those that protect sensitive areas from overuse, disturbance, or destruction (e.g., special designations for spawning areas or undisturbed natural communities);

- alternative methods of protection (e.g., new technologies for erosion control and shoreline protection, incentives for property owners to protect habitats); and

- traditional policies and regulations (e.g., enforcement, legislation, and grants).

7. Identify and restore degraded aquatic communities, working in partnership with other public and private groups to ensure success of these projects. Removal of the Woolen Mills dam and restoration of river and riparian habitat on the Milwaukee River provides an excellent template for similar projects and demonstrates that there is wide support for such activities, particularly in urban areas. Some northern rivers affected by historical log drives are among the candidates for restoration. In some projects, dredging and disposal of contaminated sediments may be necessary, and the lack of an approved hazardous waste site in Wisconsin may present problems. There is great potential for additional joint restoration projects involving state, federal, county, municipal, industrial, and citizen partners. For example, the Great Lakes Indian Fish and Wildlife Commission is interested in restoring wild rice beds. Other organizations, such as Ducks Unlimited, are interested in shallow lake restoration.

Dragonflies, such as this nymph of the extra-striped snaketail, are important indicator species for ecosystem health. *Photo by William Smith.*

8. Continue to develop a long-term inventory and monitoring program that includes the state's aquatic communities and the species dependent on aquatic systems. No agency can hope to sample all aquatic taxa in all state waters; an effective approach is to sample a statistically valid subset of waters using cost-effective biocriteria (e.g., indices of biotic integrity or abundance of environmentally sensitive species) and apply results to a well-developed waters classification system. Such a program will develop meaningful trend information and help identify problem areas in need of special protection or restoration efforts.

9. Consider the long-term, cumulative impacts of Department actions. Individual regulations or decisions may seem independent of one another, but in combination some may be inconsistent or have unintended impacts on the efforts of other programs or on aquatic resources. For example, any single macrophyte removal permit may seem minor, but the cumulative impact of many such permits may have significant effects on the ecosystem.

   a. Develop policy to establish an integrated, comprehensive approach to aquatic plant management. Three different programs are now involved in aquatic plant management, and their decisions are often based on different considerations. The Water Regulation program evaluates permits for structures such as sand blankets and mechanical weed control devices, the Lake Management program is responsible for permitting chemical and mechanical aquatic plant management proposals, and Fisheries Management is involved in the habitat issues related to both programs.

   b. Consider a pilot program for applying ecosystem management principles to selected aquatic regulatory and management programs. This would explore ways to correct problems arising when one program makes decisions that impact parts of the ecosystem managed by another program. This kind of approach might be easier to pilot for aquatic than terrestrial systems, because aquatic community boundaries are more easily defined, and they are typically already under Department management authority.

10. Work with the agricultural community and other public and private interests to address the effects of agriculture on aquatic ecosystems. Much is known about the impacts of erosion, nutrients, pesticides, and land use changes. Voluntary programs have not always been successful in mitigating these impacts but mandatory programs have not been popular. Incentives to alleviate the environmental effects of agricultural practices need greater attention in federal farm legislation and programs.

11. Emphasize critical aquatic habitat protection and restoration priorities in land acquisition and easement programs. Undeveloped shoreline areas deserve special consideration because these opportunities are rapidly declining.

12. Study the genetic composition of selected native fish species and modify fish stocking, transfer, and bait collecting policies if they appear detrimental to genetic diversity.

13. Take action at the state and federal levels to prevent the invasions of exotic species. Contingency plans would prepare the Department to be proactive when small infestations occur. Public education and awareness programs can help minimize the risk of importation and introduction.

14. Exercise extreme caution in implementing biological engineering to intensively manage the aquatic community. It is doubtful that such technology will be cost-effective or desirable when compared with the benefits of protecting naturally reproducing populations within self-sustaining ecosystems.

15. Support and conduct additional research to apply the principles of conservation biology to the management of aquatic communities and ecosystems. Many important questions remain unanswered, for instance: do rivers that have been fragmented by dams follow the principles of island biogeography? How does a lake's size affect its susceptibility to various kinds of disturbance? Is fish stocking of smaller waters more detrimental to biodiversity than stocking of larger waters?

Case Study

Habitat Restoration Following Dam Removal on the Milwaukee River at West Bend

Contributed by Mike Staggs, John Lyons, and Kris Visser

There are over 50 dams in the Milwaukee River Basin, most holding back small impoundments of 50 acres or less. Because most of these impoundments originated as mill dams, they are located in the heart of urban areas and are valued by local residents for ice skating, waterfowl viewing, and their aesthetic qualities. Ecologically, however, these impoundments fragment fish habitat, create barriers to fish movement, may create thermal pollution problems, and typically have poor water quality as a result of sedimentation and related eutrophication. In some cases, the dams are more than a century old, creating safety concerns for their public and private owners. Thus, management of these dams and their associated impoundments poses an ecologically and socially complex problem in the Milwaukee River Basin.

In West Bend, a wooden dam was built across the river as early as 1870 to operate a woolen mill. In 1919 it was replaced by a concrete dam, which was operated privately for nearly 40 years to produce hydropower. The City took ownership of the dam in 1959. By 1987, the dam was in obvious need of removal or replacement. The City either had to remove the dam and restore the associated riverbed or replace the dam in conjunction with the construction of a new bridge.

A DNR team studied the 67-acre impoundment and found siltation; poor water quality; high turbidity; low recreational values due to shallow depth; a fish population heavily dominated by carp, suckers, and bluntnose minnows; and a lack of aquatic vegetation throughout the entire impoundment. Both upstream and downstream from the impoundment, where the river still flowed freely within its banks, the fish population was dominated by a variety of minnows, darters, crappie, bluegills and other panfish, and smallmouth and largemouth bass. In the river itself, carp, suckers, and bluntnose minnows were much less abundant than in the impoundment; carp made up 83% of the catch in the impoundment but only 23% above and below it.

After considerable public discussion, the City decided to accept the Department's recommendation to remove the dam, rehabilitate the riverbed, and stock gamefish. The goal was to restore self-sustaining habitat for smallmouth bass and other native fish species, to eliminate barriers to fish migration, to improve water quality, to create an urban park along the shoreline to provide recreational opportunity, and to use cost-effective methods to achieve these goals.

The dam was removed in May 1988. After dam removal, Department managers did some habitat improvement work throughout 1989 and 1990, including removing material from a portion of the channel area; placing logs, tree root masses, boulders, and similar materials underwater to create "instant" habitat; and rip-rapping some areas to prevent erosion. However, most of the formerly impounded area was allowed to recover naturally, without management.

The impoundment in the Milwaukee River at West Bend was drawn down in February 1988 to prepare for dam removal. *Photo by Paul Kanehl.*

The restoration produced 1.5 miles of free flowing river. Fish access to one mile of river upstream from the former impoundment was also regained. Floodplain areas of the former impoundment were developed as parkland, and oaks and maples were planted along the banks. Aquatic habitat quality improved dramatically. Aquatic vegetation quickly returned. Carp populations declined, and smallmouth bass and panfish populations increased. One threatened species, the greater redhorse, is now found in this restored area of the river.

This section of the Milwaukee River was restored following dam removal in May 1988. The formerly fragmented habitat is once again a free-flowing river with abundant aquatic vegetation and a diverse fish community. This photo was taken in June 1991. *Photo by Paul Kanehl.*

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Glossary

Abiotic Environment. The nonliving components of the environment.

Adaptive Management. A formal, structured approach to dealing with uncertainty in natural resource management, using the experience of management as an ongoing, continually improving process.

Barrens. Areas of sandy soil dominated by grasses, low shrubs, and small trees and subject to frequent wildfire. In general, the barrens community takes the form of pine barrens in northern and central Wisconsin and oak barrens in southern and west-central Wisconsin. Bracken grasslands are also a part of the barrens community.

Biological Diversity. The spectrum of life forms and the ecological processes that support and sustain them. Biological diversity occurs at four interacting levels: genetic, species, community, and ecosystem. In shortened form, biological diversity is known as biodiversity.

Biosphere. The parts of the earth's surface layers, waters, and atmosphere in which living things exist.

Biotic Environment. The living components of the environment.

Biotic Province. Subdivisions of the earth's surface into geographical land units based on ecological associations of plants and animals. Also known as biomes and major life zones. Examples are tundra, northern coniferous forest, desert, grassland, and tropical forest.

Bracken-Grassland. The northern version of prairie, similar in structure but floristically very different, with bracken fern being the dominant species.

Brush Prairie. Prairie with young trees and shrubs less than 6 ft tall, maintained in this condition by repetitive fire.

Capability (Ecological). The long-term ability of an ecosystem to sustain diverse assemblages of microbial, plant, animal, and human communities and to retain the integrity of ecological composition, structure, and function under different management alternatives.

Cedar Glade. Savannas occurring on dry limestone bluffs, with red cedar more prevalent than oaks.

Climax Community. In theory, the final community in a successional series, a community that is self-perpetuating, in equilibrium with the physical habitat, and controlled by the regional climate. Disturbance and topographic and soil conditions strongly influence the species we associate with climax conditions at a particular sites.

Community. An assemblage of species living together in a particular area, at a particular time, in a prescribed habitat. Communities usually bear the name of their dominant plant species but include all of the microbes, plants, and animals living in association with the dominant plant species at a given time.

Community Diversity. The variety and type of species present in a community, the complexity of their interactions, and the age and stability of the community. The community diversity of a region is influenced by the number of communities present, the degree of difference among the communities, and how the communities are distributed across the region.

Composition. The makeup of an ecological unit in terms of the organisms or groups of organisms present in a unit area or geographical area contains.

Critical Thinking. A process of reflection and analysis that involves the identification of assumptions, the identification of existing knowledge, the exploration of alternatives, and the integration of new understandings into thought and behavior patterns. As applied to natural resource or environmental decision-making, it results in the integration of current scientific knowledge and clarified values.

Dystrophic Lakes. Nutrient-limited lakes, with low species diversity, simplified systems, and extremely low levels of energy transfer (i.e., short food chains) (also known as bog lakes).

Ecological Processes. Actions or events that link organisms and their environment. Examples are nutrient cycling, carbon cycling, predation, and primary productivity.

Ecoregion. Areas of relatively homogenous ecological systems. Ecoregions are usually based on patterns of land use, topography, present and potential natural vegetation, and soils. Ecoregion designations are used by resource managers to develop logical, regional strategies for land acquisition and management.

Ecosystem. A biotic community and its abiotic environment, considered together as a unit. Ecosystems are characterized by flow of energy that leads to trophic structure and material cycling (i.e., exchange of materials between living and nonliving parts). Ecosystem is a shortened form of the term ecological system.

Ecosystem Diversity. The diversity in structure and function within an ecosystem. It is determined by the amount and complexity of linkages among the plants and animals of an ecosystem and their abiotic environment.

Ecosystem Management. A system to assess, conserve, protect, and restore the composition, structure, and function of ecosystems, to ensure their sustainability across a range of temporal and spatial scales and to provide desired ecological conditions, economic products, and social benefits.

Edge. The zone where two different habitat types meet. It can range from an abrupt change from one to the other (hard edge) to a gradual integration of the two (soft edge).

Edge Effects. The ecological impact of interfacing two or more habitat types. Edge is inherent or natural in nature but can have negative impacts if its creation alters ecological processes. In general, edge effects increase in relation to the dissimilarity between adjoining habitats.

Environmental Pollution. The human-induced movement of many types of substances within and between air, land, and water components of ecosystems in quantities and at rates that adversely impact organisms, habitats, communities, ecosystems, or public health.

Eutrophic Lakes. Lakes that are high in nutrients but continue to show normal species diversity and ecological processes.

Fen. A highly restricted type of wet prairie that supports an unusually specialized flora. It forms on wet to moist and often peaty, calcareous soils that have developed over a diffuse groundwater discharge area that is often under artesian pressure.

Fragmentation. The breaking up of large and continuous ecosystems, communities, and habitats into smaller areas surrounded by altered or disturbed land or aquatic substrate.

Function. The roles played by the biotic and abiotic components of ecosystems in driving the processes (e.g., carbon cycle, water cycle, nutrient cycle) that sustain the ecosystem.

Genes. The functional unit of heredity—the components of DNA molecules that control heredity characteristics in organisms.

Genetic Diversity. The spectrum of genetic material carried by different organisms. Genetic diversity has the potential to increase or decrease over time due to recombination.

Geographic Information System (GIS). A system of computer hardware and software that can input, manipulate, and analyze large amounts of **geographically referenced data** to support the decision-making processes of an organization.

Geographically Referenced Data. Information that is spatially keyed to a coordinate system for the earth so that different data layers (or maps) can be overlayed or integrated. This type of data is the foundation of **Geographic Information Systems (GIS)**.

Grassland. Refers collectively to several native Wisconsin plant communities, including prairie, brush prairie, sand barrens, bracken-grassland, fen, and sedge meadow.

Habitat. The place where an organism lives and its surrounding environment, including its biotic and abiotic components. Habitat includes everything an organism needs to survive.

Hypereutrophic Lakes. Lakes that have nutrient levels so high that the functions of the system may be affected.

Interior Habitat. That portion of a community not influenced by edge effects because it is far enough removed from its outside boundaries.

Isolation Effects. The impact of isolating habitat patches from similar habitat through fragmentation.

Landscape. An area composed of adjacent and interacting ecosystems that are related because of geology, land forms, soils, climate, biota, and human influences.

Landscape Scale. The appropriate **spatial** and **temporal scale** for planning, analysis, and improvement of management activities to sustain ecosystem capability and achieve **ecosystem management** objectives.

Mesotrophic Lakes. Midway between oligotrophic and eutrophic lakes in nutrients.

Northern Forest. A Wisconsin community characterized by mixed deciduous and coniferous tree species. In broader terms, it may be characterized as a region representing the area north of the tension zone that divides Wisconsin into two distinct climatic zones.

Oak Opening. Savanna on rich, mesic soils with mostly bur or white oak.

Old Growth. A community with dominant trees at or near biological maturity. The age and structure of an old-growth community varies with species and site. Old-growth stands are sometimes characterized by a multi-layered, uneven age and size class structure; a high degree of compositional and structural patchiness and heterogeneity; and significant amounts of woody debris and tip-up mounds.

Oligotrophic Lakes. Lakes that are low in nutrients, with low levels of energy transfer and simplified systems, but not to the extent of dystrophic lakes. Oligotrophic lakes, such as Lake Superior, are often considered to be the epitome of desirable water quality conditions.

Postglacial. The period after the melting of the last glacier (the Wisconsin Glacier), from approximately 10,500 years ago up to the present.

Prairie. A plant community dominated by grasses and forbs, although woody shrubs and occasional tree seedlings may also be present. Prairies frequently grade imperceptibly into other communities such as oak savanna and sedge meadow.

Presettlement. The period before the arrival and extended presence of non-Native American people in Wisconsin.

Region. Region has no specific spatial or fixed-area definition. Like scale, the appropriate definition of region will vary according to the scope of the problem or project being considered. The geographic area included in any particular definition of region will be determined by our knowledge of the breadth of the interconnections among the biotic communities involved.

Sand Barrens. Similar to dry sand prairie, but with far sparser vegetation and generally including exposed sand or sandblows. Most sand barrens today are artifacts of post-settlement activity, primarily failed attempts at agriculture.

Savanna. A community that was historically part of a larger ecotone complex bordered by the prairies of the west and the deciduous forests of the east. This ecotone was a mosaic of plant community types that represented a continuum from prairie to forest. Savannas were the communities in the middle of this continuum. Characteristically, savannas have less than 50% crown cover.

Scale. The relative amount or degree of something. In relation to ecosystems, scale has both spatial and temporal meanings (see **spatial scale** and **temporal scale**).

Sedge Meadow. Distinguished from wet prairie by having (1) more sedge than grass vegetation, (2) more organic than mineral soil, and (3) seasonally standing water. It also supports a less diverse flora than wet prairie.

Simplification. A reduction in the diversity of genetic, species, or community resources, and a reduction in the complexity of the interrelationships within them. Simplification affects the composition, structure, and/or function of ecosystems.

Size Effects. The ecological impact of decreasing or increasing the size of land units.

Southern Forest. A community characterized by several species of oak and by the presence of several tree species normally not found north of the tension zone (i.e., shagbark hickory, hackberry, boxelder, and black walnut).

Spatial Scale. The geographic size of a community or ecosystem. Spatial scale can range from a microsite such as the underside of a leaf on the forest floor, to a forest, to the larger landscape. The biosphere (i.e., the planet earth) can be thought of as the maximum spatial scale.

Species. A group of individuals that can interbreed successfully with one another, but not with members of other groups. Plants and animals are identified as belonging to a given species based on similar morphological, genetic, and biochemical characteristics.

Species Diversity. The variety of species in an area. It includes not only the number of species in the area but also their relative abundance and spatial distribution. Species richness is one component of species diversity, but not the only determinant.

Species Richness. The number of species in an area.

Structure. The pattern or physical organization of an area. It has both vertical and horizontal components.

Succession. Progressive temporal changes in species composition, organic structure, and energy flow in a community.

Sustainability. Long-term management of **ecosystems** to meet the needs of present human populations without interruption, weakening, or loss of the resource base for future generations.

Tallgrass Prairie. The eastern portion of the grassland biome (including Wisconsin), characterized by productive soils, ample precipitation, and tall grasses as the dominant vegetation..

Temporal Scale. The time required to complete a life history event or ecological process. Temporal scale can vary from a few seconds for biochemical reactions to thousands of years for ecosystem development. For geologic changes, temporal scale reaches millions of years.

Transdisciplinary Perspective. The ability to transcend the focus and tenets of a particular discipline (e.g.,fisheries, forestry, wildlife management) to consider the widest range of options for managing a particular landscape unit.

Trophic structure. The inter-relationship of all organisms within a community food web as determined by the specific role each plays as a producer and/or consumer of energy or food resources.

Values. Principles, standards, or qualities considered worthwhile or desirable from a particular viewpoint.

Wetland. An area where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which has soils indicative of wet conditions.

APPENDIX A

Common and Scientific Names of Organisms Cited

Trees

ash, black	*Fraxinus nigra*
ash, white	*Fraxinus americana*
aspen	*Populus tremuloides*
basswood	*Tilia americana*
beech, American	*Fagus grandifolia*
birch, white	*Betula papyrifera*
birch, yellow	*Betula alleghaniensis*
boxelder	*Acer negundo*
butternut	*Juglans cinerea*
cedar, red	*Juniperus virginiana*
cedar, white	*Thuja occidentalis*
elm	*Ulmus spp.*
elm, American	*Ulmus americana*
fir, balsam	*Abies balsamea*
hackberry	*Celtis occidentalis*
hemlock	*Tsuga canadensis*
hickory, bitternut	*Carya cordiformis*
hickory, shagbark	*Carya ovata*
ironwood	*Ostrya virginiana*
maple, red	*Acer rubrum*
maple, sugar	*Acer saccharum*
oak, black	*Quercus velutina*
oak, black-jack	*Quercus marilandica*
oak, bur	*Quercus macrocarpa*
oak, Hill's = northern pin oak	*Quercus ellipsoidalis*
oak, red	*Quercus rubra*
oak, pin	*Quercus palustris*
oak, swamp white	*Quercus bicolor*
oak, white	*Quercus alba*
pine, jack	*Pinus banksiana*
pine, Norway = red pine	*Pinus resinosa*
pine, red	*Pinus resinosa*
pine, scrub	n.f. (jack pine?)
pine, white	*Pinus strobus*
spruce	*Picea spp.*
spruce, white	*Picea glauca*
spuce, black	*Picea mariana*
tamarack	*Larix laricina*
walnut, black	*Juglans nigra*

Shrubs

alder, tag	*Alnus spp.*
bearberry	*Arctostaphylos uva-ursi*
bilberry, dwarf	*Vaccinium cespitosum*
blueberry	*Vaccinium angustifolium*
also	
blueberry, low sweet	*Vaccinium angustifolium*

buckthorn, common .... *Rhamnus cathartica*

cherry, sand .... *Prunus pumila*

cranberry .... *Vaccinium macrocarpon*

gooseberry, hawthorn-leaved .... *Ribes oxyacanthoides*

hazel, beaked .... *Corylus cornuta*

honeysuckle, bush .... *Diervilla lonicera*

honeysuckle, Japanese . *Lonicera japonica*

huckleberry .... *Gaylussacia baccata*

tea, early New Jersey .... *Ceanothus herbaceus*

tea, New Jersey .... *Ceanothus americanus*

willow, sand = sandbar willow or .... *Salix exigua*

= sand-dune willow ..... *S. cordata*

yew, Canada .... *Taxus canadensis*

Forbs, Grasses, and Lower Plants

alfalfa .... *Medicago sativa*

anemone, Carolina .... *Anemone caroliniana*

anemone, Hudson Bay . *Anemone multifida*

arbutus, trailing .... *Epigaea repens*

asphodel, false .... *Tofieldia glutinosa*

aster family .... *Asteraceae [Compositae]*

aster, forked .... *Aster fureatus*

beardtongue, hairy .... *Penstemon hirsutus*

beardtongue, pale .... *Penstemon pallidus*

bellwort, sessile .... *Uvularia sessilifolia*

bladderpod .... *Lesquerella ludoviciana*

blazing star, marsh .... *Liatris spicata*

blazing star, dotted .... *Liatris punctata*

bluegrass, bog .... *Poa paludigena*

bluegrass, Kentucky ..... *Poa praetensis*

bluets .... *Houstonia caerulea*

boneset, woodland .... *Eupatorium sessilifolium*

broomrape, Louisiana .. *Orobanche ludoviciana*

broomrape, one-flowered .... *Orobanche uniflora*

bulrush, tussock .... *Scirpus cespitosus*

bush-clover, prairie ...... *Lespedeza leptostachya*

bush-clover, slender ..... *Lespedeza virginica*

clover, villous prairie .... *Petalostemum villosum*

coneflower, pale purple *Echinacea pallida*

cow-wheat .... *Melampyrum lineare*

cress, European water .. *Rorippa nasturtium-aquaticum*

dandelion, prairie .... *Agoseris cuspidata*

eupatorium, sessile-leaved .... *Eupatorium sessilifolium*

fame-flower, prairie ...... *Talinum rugospermum*

fern, bracken .... *Pteridium aquilinum*

fern, Braun's holly .... *Polystichum braunii*

fern, goblin .... *Botrychium mormo*

fern, sweet .... *Myrica asplenifolia*

fern, ternate grape .... *Botrychium ternatum*

fescue, western .... *Festuca occidentalis*

foamflower .... *Tiarella cordifolia*

foxglove, eared false ..... *Tomanthera ariculata*

foxglove, mullein .... *Dasistoma macrophylla*

foxglove, pale false .... *Agalinis skinneriana*

foxglove, round-stemmed false .... *Agalinis gattingeri*

gentian, cream .... *Gentiana sp. n.f.*

gentian, horse .... *Triosteum spp.*

gentian, prairie .... *Gentiana puberula*

gentian, small fringed ... *Gentianopsis procera*

gentian, yellowish .... *Gentiana alba*

giant hyssop, yellow ..... *Agastache nepetoides*

goldenrod, elm-leaved .. *Solidago ulmifolia*

goldenrod, Ohio .... *Solidago ohioensis*

grass, beak = beak-rush or	*Rhynchospora spp.*
= beaked spike-rush	*Eleocharis rostellata*
grass, brome	*Bromus spp.*
grass family	Gramineae
grass, poverty	*Aristida dichotoma*
grass, quack	*Elytrigia repens*
grass, reed canary	*Phalaris arundinacea*
grass, Smith melic	*Melica smithii*
grass, Wilcox's panic	*Panicum Wilcoxianum*
grass-of-parnassus	*Parnassia spp.*
grass-of-parnassus, marsh	*Parnassia palustris*
grass-of-parnassus, small-flowered	*Parnassia parviflora*
groundcherry, white	*Physalis grandiflora*
hairgrass, common	*Deschampsia ?flexuosa?*
heath family	*Ericaeae [Ericaceae]*
hyacinth, wild	*Camassia scilloides*
indigo, false wild	*Baptisia spp.*
iris, dwarf lake	*Iris lacustris*
kitten tails	*Besseya bullii*
lady-slipper, ram's head	*Cypripedium arietinum*
lady-slipper, white	*Cypripedium candidum*
lead plant	*Amorpha canescens*
legume family	Fabaceae
lespedeza, Virginia	*Lespedeza virginica*
lettuce, great white	*Prenanthes crepidinea*
lettuce, rough white	*Prenanthes aspera*
lily family	Liliaceae
loco weed, Fassett's	*Oxytropis campestris v: chartacea*
loosestrife, purple	*Lythrum salicaria*
lupine	*Lupinus perennis*
mallow, glade	*Napaea dioica*
mallow, poppy	*Callirhoe triangulata*
marsh-marigold, floating	*Caltha natans*
milfoil, Eurasian water	*Myriophyllum spicatum*
milkweed, Mead's	*Asclepias meadii*
milkweed, prairie	*Asclepias sullivantia*
milkweed, purple	*Asclipias purpurascens*
milkweed, tall	*Asclipias exaltata*
milkweed, wooly	*Ascplepias lanuginosa*
milkwort, cross	*Polygala cruciata*
milkwort, pink	*Polygala incarnata*
moonwort	*Botrychium lunaria*
moss, reindeer	*Cladonia spp.*
nutrush, netted	*Scleria reticularis*
orchid, calypso	*Calypso bulbosa*
orchid, Hooker's	*Platanthera hookeri*
orchid, prairie white-fringed	*Platanthera leucophaea*
orchid, small round-leaved	*Platanthera orbiculata*
orchid, tubercled	*Platanthera flava*
orchid, white-fringed	*Platanthera blephariglottis*
parsley, prairie	*Polytaenia nuttallii*
parsnip	*?Pastinaca sativa?*
pea, beach	*Lathyrus maritimus*
pea, silvery scurfy	*Psoralea argophylla*
petunia, wild	*Ruellia humilis*
phlox, smooth	*Phlox glaberrima*
pimpernel, yellow	*Taenidia integerrima*
pine-drops	*Pterospora andromedea*
plantain, pale Indian	*Cacalia atriplicifolia*
plantain, prairie Indian	*Cacalia tuberosa*
plum, prairie	*Astragalus crassicarpus*

pomme-de-prairie .... *Psoralea esculenta*
prickly pear, brittle ...... *Opuntia fragilis*
primrose, toothed evening .... *Oenothera serrulatus*
puccoon, hoary .... *Lithospermum canescens*
quinine, wild .... *Parthenium integrifolium*
redroot .... *Ceanothus ovatus*
reed, sand .... *Calamovilfa longifolia*
rice, wild .... *Zizania aquatica*
rose family .... *Rosaceae*
rush, bald .... *Juncus sp. n.f.*
rush, bog .... *Juncus sp. n.f.*
rye, downy wild .... *Elymus villosus*
sagewort, prairie .... *Artemisia frigida*
sedge, chestnut .... *Fimbristylis puberula*
sedge, coast .... *Carex sp. n.f.*
sedge, crow-spur .... *Carex sp. n.f.*
sedge, drooping .... *Carex prasina*
sedge, hop-like .... *Carex sp. n.f.*
sedge, lenticular .... *Carex lenticularis*
sedge, Michaux's .... *Carex michauxiana*
sedge, prairie straw ...... *Carex suberecta*
sedge, Richardson's ...... *Carex richardsonii*
sedge, Torrey's .... *Carex torreyi*
senna, Maryland .... *Cassia marilandica*
shinleaf, small .... *Pyrola minor*
skullcap, small .... *Scutellaria parvula*
spike-rush, angle stemmed = angled s-r ... *Eleocharis quadrangulata*
spike-rush, beaked .... *Eleocharis rostellata*
spike-rush, Robbin's ..... *Eleocharis robbinsii*
spike-rush, wolf .... *Eleocharis wolfii*
spurge, leafy spurge ..... *Euphorbia esula*
St. John's wort, round-fruited .... *Hypericum sphaerocarpum*
sundew, English .... *Drosera anglica*
sundew, linear leaved ... *Drosera linearis*
sweetfern .... *Comptonia peregrina*
switchgrass .... *Panicum virgatum*
thistle, Canada .... *Cirsium arvense*
thistle, dune .... *Cirsium pitcheri*
thistle, prairie .... *Cirsium hillii*
thistle, tall .... *Cirsium altissimum*
thistle, woodland .... *Cirsium sp. n.f.*
twayblade, auricled ...... *Listera auriculata*
twayblade, broad-leaved .... *Listera convallarioides*
valerian, marsh .... *Valeriana sitchensis uliginosa*
vetch, Cooper's milk ..... *Astragalus neglectus*
violet, sand .... *Viola adunca*
wintergreen .... *Gaultheria procumbens*

Mammals

badger .... *Taxidea taxus*
bear, black .... *Euarctos americanus*
beaver .... *Castor canadensis michiganensis*
bison .... *Bison bison*
bobcat .... *Lynx rufus*
caribou, woodland .... *Rangifer caribou*
cougar .... *Felis concolor*
coyote .... *Canis latrans*
deer, white-tailed .... *Odocoileus virginianus*
elk .... *Cervus canadensis*
fisher .... *Martes pennanti*
fox, red .... *Vulpes fulva*
ground squirrel, Franklin's .... *Citellus franklinii*
ground squirrel, thirteen-lined .... *Citellus tridecemlineatus*
hare, snowshoe .... *Lepus americanus*

lynx	*Lynx canadensis*
marten, pine	*Martes americana*
mice	*Peromyscus spp.*
mink	*Mustela vison*
mole, prairie	*Scalopus aquaticus*
moose, northwestern	*Alces alces*
mouse, harvest	*Reithrodontomys megalotis*
mouse, prairie deer	*Peromyscus maniculatus*
mouse, white-footed	*Peromyscus leucopus noveboracensis*
muskrat	*Ondatra zibethicus*
otter	*Lutra canadensis*
pocket gopher, plains	*Geomys bursarius*
porcupine	*Erethizon dorsatum*
rabbit, cottontail	*Sylvilagus floridanus*
rabbit, white-tailed jack	*Lepus townsendii*
raccoon	*Procyon lotor*
shrew, least	*Cryptotis parva*
shrew, masked	*Sorex cinereus*
shrew, short-tailed	*Blarina spp.*
shrews	*Blarina spp. and Sorex spp.*
skunk, striped	*Mephitis mephitis*
squirrel, flying	*Glaucomys sabrinus macrotis*
squirrel, fox	*Sciurus niger*
squirrel, gray	*Sciurus carolinensis*
squirrel, red	*Tamiasciurus hudsonicus*
vole, prairie	*Microtus ochrogaster*
voles	*Microtus spp.*
weasel, long-tailed	*Mustela frenata*
wolf, timber	*Canis lupus*
wolverine	*Gulo luscus luscus*
woodchuck	*Marmota monax*

Birds

blackbird, Brewer's	*Euphagus cyanocephalus*
blackbird, red-winged	*Agelaius phoeniceus*
bluebird, eastern	*Sialia sialis*
bobolink	*Dolichonyx oryzivorus*
bunting, indigo	*Passerina cyanea*
catbird, gray	*Dumetella carolinensis*
chickadee, black-capped	*Parus atricapillus*
chickadee, boreal	*Parus hudsonicus*
cormorant, double-crested	*Phalacrocorax auritus*
cowbird, brown-headed	*Molothrus ater*
crane, sandhill	*Grus canadensis*
crane, whooping	*Grus americana*
creeper, brown	*Certhia americana*
crossbill, red	*Loxia curvirostra*
crossbill, white-winged	*Loxia leucoptera*
crow, American	*Corvus brachyrhynchos*
cuckoo, black-billed	*Coccyzus erythropthalmus*
cuckoo, yellow-billed	*Coccyzus americanus*
curlew, long-billed	*Numenius americanus*
dickcissel	*Spiza americana*
dove, mourning	*Zenaida macroura*
eagle, bald	*Haliaeetus leucocephalus*
finch, purple	*Carpodacus purpureus*
flicker, northern	*Colaptes auratus*
flycatcher, acadian	*Empidonax virescens*
flycatcher, great crested	*Myiarchus crinitus*

flycatcher, least .... *Empidonax minimus*
flycatcher, olive-sided .. *Contopus borealis*
goldfinch, American ..... *Carduelis tristis*
goshawk, northern .... *Accipiter gentilis*
grackle, common .... *Quiscalus quiscula*
grosbeak, evening .... *Coccothraustes vespertinus*
grosbeak, pine .... *Pinicola enucleator*
grosbeak, rose-breasted .... *Pheucticus ludovicianus*
grouse, ruffed .... *Bonasa umbellus*
grouse, sharp-tailed ...... *Tympanuchus phasianellus*
grouse, spruce .... *Dendragapus canadensis*
gulls .... *Larus spp.*
harrier, northern .... *Circus cyaneus*
hawk, broad-winged .... *Buteo platypterus*
hawk, Cooper's .... *Accipiter cooperii*
hawk, red-shouldered .. *Buteo lineatus*
hawk, sharp-shinned ... *Accipiter striatus*
jay, blue .... *Cyanocitta cristata*
jay, gray .... *Perisoreus canadensis*
junco, dark-eyed .... *Junco hyemalis*
kestrel, American .... *Falco sparverius*
killdeer .... *Charadrius vociferus*
kingbird, eastern .... *Thrannus tyrannus*
kinglet, golden-crowned .... *Regulus satrapa*
kinglet, ruby-crowned .. *Regulus calendula*
kite, swallow-tailed ...... *Elanoides forficatus*
lark, horned .... *Eremophila alpestris*
loon, common .... *Gavia immer*
meadowlark, eastern .... *Sturnella magna*
meadowlark, western ... *Sturnella neglecta*
merlin .... *Falco columbarius*
night-heron, yellow-crowned .... *Nyctanassa violacea*
nighthawk, common .... *Chordeiles minor*
nuthatch, red-breasted .... *Sitta canadensis*
nuthatch, white-breasted .... *Sitta carolinensis*
oriole, orchard .... *Ictreus spurius*
osprey .... *Pandion haliaetus*
ovenbird .... *Seiurus aurocapillus*
owl, barn .... *Tyto alba*
owl, barred .... *Strix varia*
owl, great horned .... *Bubo virginianus*
owl, long-eared .... *Asio otus*
owl, northern saw-whet .... *Aegolius acadicus*
owl, short-eared .... *Asio flammeus*
parakeet, Carolina .... *Conuropsis carolinensis*
parula, northern .... *Parula americana*
phalarope, Wilson's ...... *Phalaropus tricolor*
pheasant, ring-necked .. *Phasianus colchicus*
phoebe, eastern .... *Sayornis phoebe*
pigeon, passenger .... *Ecopistes migratorius*
pintail, northern .... *Anas acuta*
plover, piping .... *Charadrius melodus*
prairie chicken, greater .... *Tympanuchus cupido*
quail, bobwhite .... *Colinus virginianus*
rail, black .... *Laterallus jamaicensis*
rail, yellow .... *Coturnicops noveboracensis*
raven, common .... *Corvus corax*
redstart, American .... *Setophaga ruticilla*
robin, American .... *Turdus migratorius*
sandpiper, upland .... *Bartramia longicauda*
sapsucker, yellow-bellied .... *Sphyrapicus varius*
shrike, loggerhead .... *Lanius ludovicianus*
sparrow, chipping .... *Spizella passerina*
sparrow, clay-colored ... *Spizella pallida*
sparrow, field .... *Spizella pusilla*

sparrow, grasshopper ... *Ammodramus savannarum*

sparrow, Henslow's .... *Ammodramus henslowii*

sparrow, lark .... *Chondestes grammacus*

sparrow, Le Conte's ...... *Ammodramus leconteii*

sparrow, savannah .... *Passerculus sandwichensis*

sparrow, sharp-tailed .... *Ammodramus caudacutus*

sparrow, song .... *Melospiza melodia*

sparrow, vesper .... *Pooecetes gramineus*

tanager, scarlet .... *Piranga olivacea*

teal, blue-winged .... *Anas discors*

tern, least .... *Sterna antillarum*

thrasher, brown .... *Toxostoma rufum*

thrush, hermit .... *Catharus guttatus*

thrush, Swainson's........ *Catharus ustulatus*

thrush, wood .... *Hylocichla mustelina*

towhee, rufous-sided .... *Pipilo erythrophthalmus*

turkey .... *Meleagris gallopavo*

veery .... *Catharus fuscescens*

vireo, Bell's .... *Vireo bellii*

vireo, red-eyed .... *Vireo olivaceus*

vireo, solitary .... *Vireo solitarius*

vireo, warbling .... *Vireo gilvus*

vireo, yellow-throated .. *Vireo flavifrons*

warbler, black-and-white .... *Mniotilta varia*

warbler, black-throated blue ...... *Dendroica caerulescens*

warbler, black-throated green .... *Dendroica virens*

warbler, Blackburnian .. *Dendroica fusca*

warbler, Canada .... *Wilsonia canadensis*

warbler, Cape May .... *Dendroica tigrina*

warbler, cerulean .... *Dendroica cerulea*

warbler, chestnut-sided .... *Dendroica pensyvanica*

warbler, Connecticut .... *Oporornis agilis*

warbler, golden-winged .... *Vermivora chrysoptera*

warbler, Kirtland's .... *Dendroica kirtlandii*

warbler, magnolia .... *Dendroica magnolia*

warbler, mourning .... *Oporornis philadelphia*

warbler, Nashville .... *Vermivora ruficapilla*

warbler, Tennessee .... *Vermivora peregrina*

warbler, yellow-rumped .... *Dendroica coronata*

warbler, yellow-throated .... *Dendroica dominica*

waterthrush, northern .. *Seiurus noveboracensis*

waxwing, cedar .... *Bombycilla cedrorum*

whip-poor-will .... *Caprimulgus vociferus*

wood-pewee, eastern ... *Contopus virens*

woodcock, American ... *Scolopax minor*

woodpecker, black-backed................ *Picoides arcticus*

woodpecker, downy ..... *Picoides pubescens*

woodpecker, hairy .... *Picoides villosus*

woodpecker, pileated ... *Dryocopus pileatus*

woodpecker, red-headed .... *Melanerpes erythrocephalus*

wren, sedge .... *Cistothorus platensis*

wren, winter .... *Troglodytes troglodytes*

yellowthroat, common .... *Geothlypis trichas*

Amphibians and Reptiles

bullsnake .... *Pituophis melanoleucus*

frog, Blanchard's cricket .... *Acris crepitans blanchardi*

frog, chorus .... *Pseudacris triseriata triseriata*

frog, green .... *Rana clamitans melanota*

frog, mink .... *Rana septentrionalis*

frog, wood .... *Rana sylvatica*

lizard, western slender glass .... *Ophisaurus attenuatus*

newt, central .... *Notophthalmus viridescens*

racer, blue .... *Coluber constrictor foxi*

racerunner, six-lined .... *Cnemidophorus sexlineatus*

rattlesnake, eastern massasauga .... *Sistrurus catenatus*

rattlesnake, timber .... *Crotalus horridus*

salamander, blue-spotted .... *Ambystoma laterale*

salamander, eastern tiger .... *Ambystoma tigrinum*

salamander, four-toed .. *Hemidactylium scutatum*

salamander, red-backed .... *Plethodon cinereus*

salamander, spotted ..... *Ambystoma maculatum*

skink, five-lined .... *Eumeces fasciatus*

skink, northern prairie .... *Eumeces septentrionalis*

snake, black rat .... *Elaphe obsoleta*

snake, Dekay's (also brown snake) .... *Storeria dekayi*

snake, eastern hognose .... *Heterodon platyrhinos*

snake, eastern milk ...... *Lampropeltis triangulum*

snake, Eastern plains garter .... *Thamnophis radix radix*

snake, northern ribbon .... *Thamnophis sauritus septentrionalis*

snake, northern red-bellied .... *Storeria occipitomaculata*

snake, queen .... *Regina septemvittata*

snake, ringneck

= prairie .... *Diadophis punctatus arnyi*

= northern .... *Diadophis punctatus edwarsi*

snake, smooth green .... *Opheodrys vernalis*

snake, western fox .... *Elaphe vulpina*

toad, American .... *Bufo americanus*

treefrog, Cope's gray ..... *Hyla chrysoscelis*

treefrog, grey = Cope's gray treefrog or Eastern gray treefrog .... *Hyla versicolor*

treefrog, wood = wood frog .... *Rana sylvatica*

turtle, Blandings .... *Emydoidea blandingi*

turtle, common snapping .... *Chelydra serpentina*

turtle, ornate box .... *Terrapene ornata*

turtle, wood .... *Clemmys insculpta*

Fish

alewife .... *Alosa pseudoharengus*

bass, smallmouth .... *Micropterus dolomieui*

bass, white .... *Morone chrysops*

bass, yellow .... *Morone mississippiensis*

bloater .... *Coregonus hoyi*

bowfin .... *Amia calva*

buffalo, bigmouth .... *Ictiobus cyprinellus* bullhead .... *Ictaluridae*

burbot .... *Lota lota*

carp, common .... *Cyprinus carpio*

carp, grass .... *Ctenopharyngodon idella*

catfish, channel .... *Ictalurus punctatus*

chub, gravel .... *Erimystax x-punctatus*

chubs .... *Corgenonus spp.*

chubsucker, creek .... *Erimyzon oblongus*

cisco, blackfin .... *Coregonus nigripinnis*

cisco, deepwater .... *Coregonus johannae*

cisco, shortjaw .... *Coregonus zenithicus*

cisco, shortnose .... *Coregonus reighardi*

dace, southern redbelley .... *Phoxinus erythrogaster*

darter, bluntnose .... *Etheostoma chlorosomum*

darter, crystal .... *Ammocrypta asprella*

darter, fantail .... *Etheostoma flabellare*

darter, gilt .... *Percina evides*

darter, Iowa .... *Etheostoma exile*

darter, Johnny .... *Etheostoma nigrum*

darter, least .... *Etheostoma microperca*

darter, mud .... *Etheostoma asprigene*

eel, American .... *Anguilla rostrata*

freshwater drum .... *Aplodinotus grunniens*

gar, longnose .... *Lepisosteus osseus*

gar, shortnose .... *Lepisosteus platostomus*

goldfish .... *Carassius auratus*

grayling .... *Thymallus arcticus*

herring, lake .... *Coregonus artedii*

herring, skipjack .... *Alosa chrysochloris*

kiyi .... *Coregonus kiyi*

lamprey, American brook .... *Lampetra appendix*

lamprey, sea .... *Petromyzon marinus*

minnow, bluntnose ...... *Pimephales notatus*

minnow, bullhead .... *Pimephales vigilax*

minnow, Ozark .... *Notropis nubilus*

minnow, suckermouth . *Phenacobius mirabilis*

mudminnow, central .... *Umbra limi*

muskellunge .... *Esox masquinongy*

northern pike .... *Esox lucius*

paddlefish .... *Polyodon spathula*

perch, white .... *Morone americana*

perch, yellow .... *Perca flavescens*

redhorse, black .... *Moxostoma duquesnei*

redhorse, golden .... *Moxostoma erythrurum*

redhorse, river .... *Moxostoma carinatum*

redhorse, shorthead ..... *Moxostoma macrolepidotum*

ruffe .... *Gymnocephalus cernua*

salmon .... *Oncorhynchus spp.*

salmon, Atlantic .... *Salmo salar*

sauger .... *Stizostedion canadense*

sculpin .... Cottidae

shad, Ohio = Alabama shad .... *Alosa alabamae*

shiner, bigmouth .... *Notropis dorsalis*

shiner, ghost .... *Notropis buchanani*

shiner, ironcolor .... *Notropis chalybaeus*

shiner, pallid .... *Notropis amnis*

shiner, pugnose .... *Notropis anogenus*

shiner, redfin .... *Notropis umbratilis*

shiner, sand .... *Notropis stramineus*

shiner, spotfin .... *Notropis spilopterus*

shiner, striped .... *Notropis chrysocephalus*

smelt, rainbow .... Osmeridae

stickleback .... *Gasterosteidae*

stoneroller, central .... *Campostoma anomalum*

sturgeon, lake .... *Acipenser fluvescens*

sturgeon, shovelnose .... *Scaphirhynchus platorynchus*

sucker, blue .... *Cycleptus elongatus*

sucker, northern hog .... *Hypentelium nigricans*

sucker, white .... *Catostomus commersoni*

sunfish, green .... *Lepomis cyanellus*

sunfish, longear .... *Lepomis megalotis*

topminnow, starhead .... *Fundulus notti*

trout .... Salmonidae

trout, brook .... *Salvelinus fontinalis*

trout, rainbow .... *Oncorhynchus mykiss*

walleye .... *Stizostedion vitreum*

Insects

butterfly, American copper .... *Lycaena phlaeas americana*

butterfly, brown elfin .... *Incisalia augustinus*

butterfly, chryxus arctic .... *Oeneis chryxus strigulosa*

butterfly, cobweb skipper .... *Hesperia metea*

butterfly, coral hairstreak .... *Harkenclenus titus*

butterfly, dusted skipper .... *Atrytoropsis hianna*

butterfly, Edward's hairstreak .... *Satyrium edwardsii*

butterfly, European cabbage .... *Pieris rapae*

butterfly, frosted elfin ... *Incisalia irus*

butterfly, Gorgone checkerspot .... *Charidryas gorgone carlota*

butterfly, Henry's elfin .. *Incisalia henrici*

butterfly, hoary elfin ..... *Incisalia polia*

butterfly, Indian skipper .... *Hesperia sassacus*

butterfly, Juvenal's dusky wing .... *Erynnis juvenalis*

butterfly, Karner blue ... *Lycaeides melissa samuelis*

butterfly, Laurentian skipper .... *Hesperia comma laurentina*

butterfly, Leonard's skipper .... *Hesperia leonardus leonardus*

butterfly, mustard white .... *Pieris napi oleracea*

butterfly, northern blue .... *Lycaeidesidas nabokovi*

butterfly, Olympian marble .... *Euchloe olympia*

butterfly, Persius dusky wing .... *Erynnis persius*

butterfly, pine elfin .... *Incisalia niphon clarki*

butterfly, pink-edged sulphur .... *Colias interior*

butterfly, Powesheik skipper .... *Oarisma powesheik*

butterfly, regal fritillary . *Speyeria idalia*

butterfly, roadside skipper .... *Amblyscirtes vialis*

butterfly, silvery blue .... *Glaucopsyche lygdamus couperi*

butterfly, sleepy dusky wing .... *Erynnis brizo*

butterfly, swamp metalmark .... *Calephelis muticum*

butterfly, tawny crescent .... *Phyciodes batesii*

butterfly, western tailed blue .... *Everes amyntula*

dragonfly .... *Anisoptera* moth, graceful clearwing .... *Hemaris gracilis*

moth, Nevada buck ...... *Hemileuca nevadensis*

moth, phlox flower ...... *Schinia indiana*

moth, pink prominent . *Hyparpax aurora*

moth, silphium borer ... *Papaipema silphii*

moth, Sprague's pygarctia .... *Pygarctia spraguei*

[moth] .... *Grammia celia*

[moth] .... *Heliothis borealis*

Other Invertebrates

clam, Asiatic .... *Corbicula fluminea*

clam, winged mapleleaf .... *Quadrula fragosa*

hydra .... *Hydra spp.*

jellyfish .... *Scyphozoa*

mussel, ebony shell ...... *Fusconaia ebena*

mussel, zebra .... *Oreissena polymorpha*

rusty crayfish .... *Orconectes rusticus*

sponge .... *Porifera*

[cladoceran] .... *Bythotrephes cederstroemi*

APPENDIX B

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