State of Wisconsin
Department of Natural Resources

Old-growth and Old Forests Handbook

2480.5

INDEX

(Chapters 13 through 17, and 19 through 50 are still in development)

FOREWORD

The purpose of this handbook is to provide guidance for the management of old-growth forests. Old-growth forests are valued for many ecological, social and economic purposes. Old-growth forests in Wisconsin are rare. They were well represented in the mid 1800's, but were mostly harvested and either replaced by younger forests (often of different species composition) or converted to other land uses. Current forests will change with time, and can provide an opportunity to restore old growth forests at the stand level and in some places at a landscape scale. Old-growth forests are desired by some forest landowners, hence the need to provide management guidance for old-growth forest maintenance where they may exist and for developing old-growth forests where they are desired as a management goal.

In May of 1995, the Department of Natural Resources formally recognized and encouraged the management of old-growth forests in *Wisconsin's Biodiversity as a Management Issue*. In 2001, Wisconsin's state land master planning process was formalized in Chapter NR 44, Wis. Adm. Code, which delineates a variety of land classifications and includes old-growth forest consideration. Master plans for state lands continue to identify this desired forest condition as a management goal and objective in designated areas of forested properties. The desire for old-growth forests was further articulated in the statewide forest planning process, completed in 2004, confirming this desired condition for a variety of forestland and ownerships. Given this last decade of consideration of old-growth forests, it has become critical to develop and maintain best available information regarding the management of old-growth. The information presented in this handbook was compiled from literature relevant to old-growth in the Lake States. The guidelines are meant to be adaptive, and are expected to change over time as more experience is gained and scientific knowledge is built. Guidance was developed by an integrated team of professionals representing various programs and disciplines within the Department of Natural Resources.

This handbook begins with a discussion of why old-growth is important from an ecological, economic and social perspective. It then transitions into technical information focused first on definitions. The definitions begin with the natural science-based old-growth characterization of "ecological" classifications followed by the more landowner goal directed "management" classifications. The ecological classifications are critical to the characterization of stands and landscapes; the management classes are critical to determining the management direction. Together these classifications communicate existing conditions and a path for resource professionals guiding future passive or active management prescriptions. Following definitions, a number of longer lived forest cover types are examined. These discussions of forest cover types are stand based. Further into the handbook, additional attention is given to landscape level management. In time, inventory information on old-growth will be presented. Finally, a glossary of terms is provided.

The management recommendations are basic guidelines. Land managers may adapt them to accommodate conditions specific to the stand or landscape being managed. These guidelines are based on research and general scientific and silvicultural knowledge of the species being managed. They are not rules for every situation. They are subject to purposeful, on-the-ground modification by the land manager. Adaptive management, based on local conditions, experience and scientific knowledge, is encouraged.

This document is intended solely as guidance and does not contain any mandatory requirements except where requirements found in statute or administrative rule are referenced. This guidance does not establish or affect legal rights or obligations, and is not finally determinative of any of the issues addressed. This guidance cannot be relied upon and does not create any rights enforceable by any party in litigation with the State of Wisconsin or the Department of Natural Resources. Any regulatory decisions made by the Department of Natural Resources in any matter addressed by this guidance will be made by applying the governing statutes and administrative rules to the relevant facts.

CHAPTER 1

WHY OLD-GROWTH AND OLD FORESTS ARE IMPORTANT

As knowledge of forest ecosystems increases, "old growth" stands are becoming a recommended component of many forest management plans. The *Wisconsin Statewide Forest Plan* (2004) recommends protection of existing relict old-growth forests. This plan also encourages increasing the number of old-growth stands, where feasible. *Wisconsin's Biodiversity as a Management Issue* (1995) recommends development of an old-growth policy. While old-growth is one facet of a broader forest ecosystem management issue, it is a very important facet, and it is needed to complete the diverse range of habitats required in sustainable forest management.

Specific ecological values of old-growth forests in Wisconsin and the eastern United States are not known as well as similar forests in the Pacific Northwest and northern Europe. Nevertheless, the limited knowledge we do have indicates that there are several benefits to considering old-growth. There are ecological, economic, and social advantages associated with landscapes that contain old forests and old-growth as an integral element.

Benefits

People value forests for numerous reasons. They rely on forests for their livelihoods, recreation, spiritual renewal, a vast array of forest products, and other essential functions. These values may be found in old-growth forests, as well. To ensure that our children and grandchildren are able to experience the same forest-based values that we enjoy today, it is imperative that we work together to sustain old-growth forests.

Ecological

Our local understanding of old-growth forest attributes and characteristics has greatly increased with recent research. The Wisconsin Department of Natural Resources in cooperation with the University of Wisconsin, completed the first phase of a comparison between old-growth and managed northern hardwood and hemlock/hardwood forests in the Great Lakes States. This was accomplished by establishing baseline information from both old-growth forests and managed stands. Results from the 1993 – 1999 fieldwork illustrate that there are many important characteristics found in old forests and old-growth stands. These include:

- The highest levels of large coarse woody debris.
- The greatest density of standing large (>12 in) snags.
- The highest populations of polypore and corticoid fungi, including *Cristinia muscida*, found only in old-growth stands
- Greater levels of macrolichen (especially nitrogen-fixing) species than managed stands.
- A distinct assemblage of bird species.
- Particular assemblages of beetles.
- Twenty species of spider were collected in old-growth, but not collected in managed stands.

Studies from other eastern northern hardwood and hemlock/hardwood old-growth forest systems indicate similar attributes and characteristics (Borman and Likens 1979, Barnes 1989, Davis 1996). Especially important are large woody debris, large standing snags, large crowns and branches, furrowed and loose bark, and microclimatic effects. DeGraaf and Rudis (1987) found significant differences in some bird species densities between old-growth forest and managed mature forests. Brown Creepers were twice as abundant in old-growth stands as in managed forests owing to their preference for loose bark on trunks. Large crowns are an apparent habitat preference for Black-throated Green Warblers, which are 3.5 times more abundant in old-growth versus managed stands. Large woody debris can double the abundance of Winter Wren. Swainson's Thrush is more abundant in old-growth than in managed forest. In southern Wisconsin complementary examples are found with Cerulean Warbler, Hooded Warbler, and Acadian Flycatcher reaching their highest densities in old forests (State Natural Area Breeding Bird Survey, DNR unpublished data).

Several species of forest herbs similarly attain their highest densities in old-growth situations (Meier et al. 1995). Species such as dwarf ginseng, Goldie's fern, violet wood sorrel, squirrel corn, and cucumber-root have higher importance values in old-growth than managed forest. Similarly, some species of fungi, bacteria, insects, soil fauna, and fish have higher species richness in old-growth than managed forest (Amaranthus 1996; Wallis et al. 1994; Timoney and Robinson 1996). Some herbs have low reproduction rates, poor seed dispersal mechanisms, or slow growth. Thus, it can take decades to reestablish their former extent after disturbance. In some instances it may take centuries for some herbs to reestablish on sites converted to row crop agriculture [for example, significant differences in ground layer herb diversity were found 80 years post disturbance (Matlack 1994)]. Even selective harvest may reduce densities of patchily occurring herbs (Meier et al. 1995).

Old-growth forests provide several important habitat features for mammals, including escape cover, maternity sites, and winter dens. Forest mammals, such as tree bats and flying squirrels, benefit in a variety of ways from microhabitats in old-growth forests. These benefits include security, energy savings, permanence, food, water, thermal stability and flexibility in denning. For some species, like American marten, availability of old forest components may be critical for survival, because they are rarely found in stands without abundant debris.

In the Upper Midwest, there are some 350 species of terrestrial vertebrates as well as thousands of species of invertebrates. Each one of these species has particular habitat needs. The conservation of plants and animals that live in forests require maintaining a representation of all the various compositional and structural elements of forests including open barrens, large clearcuts, mature forests, and old-growth forests. Currently, both open barrens and old-growth forests are rare and in need of conservation.

The ecological values of old-growth are extensive and broad-based and are derived from scientific baseline/benchmark studies of hydrology, forest soils, structure, productivity, nutrient cycling and food webs (Whitney 1987). For example, dendrochronology studies in old-growth stands provide information on past changes in rainfall, temperature, stream flow, forest fires, insect outbreaks, pollution, and other processes (Swetnam and Brown 1992). Research natural areas and state natural areas in many instances establish reference sites in old-growth stands to focus long-term ecological research. These long-term study sites provide a scientific basis for ecological sustainability. Each of these numerous studies has proven invaluable to both our collective scientific knowledge and to our understanding of how human activities affect ecosystems.

Benchmarks (ecological reference areas) are places on the landscape managed primarily for their ecological values. Management considerations for production of forest products, wildlife habitat for game species, recreational activities, and other natural resource objectives are secondary, though some may be compatible with benchmark management. Benchmarks provide a framework for improving our understanding of ecological systems and changes occurring within them, as well as for evaluating the consequences of management actions and the impacts, past and present, of humans on the landscape. They can also provide an historical ecological context to bridge the past with the present. Benchmarks for some natural community types are generally older, later developmental stages still subjected to some of the natural processes with which they developed and requiring little or no active management. Other types require active management that reintroduces or mimics a natural process now absent from the landscape.

Economic

Forests provide ecosystem services that have direct economic values as a source of materials, food, and medicines. Old forests may provide different types and amounts of services and supplies. For example, managing for older forests may reduce total timber volume yields, but could increase yields of large sawtimber and veneer.

Every year, more people seek the solitude an old-growth forest can provide. Local businesses, including lodging, food, and automotive services, can directly benefit when these users visit the old-growth forest (WDNR 1999). Wisconsin nature-based tourism is a multi-billion dollar industry that is growing nearly every year (WDOTourism 2005). Furthermore, nationwide, the nature-based tourism industry is diversified and increasingly including those seeking old-growth forests (US EPA 2004). Nature reserves, including old-growth, combined with the forest products industry tend to diversify and stabilize local northern economies (Tyrvainen et al. 2005 in press, Canadian Parks and Wilderness Society 2001).

Spin-off businesses like guide services can add to the local tax base. Sales of site guides, maps and gear can add to the local economy. Researchers and education groups should increase their use of these areas. While working or learning at natural sites, these groups may use similar services as those who recreate there.

Social

Old-growth forests provide inspirational, aesthetic and philosophical values to humans and have helped shape our history and culture. Some people feel a connection to them, believing they are a significant natural feature and a key part of Wisconsin's heritage. Prominent authors, such as John Muir, Aldo Leopold, and Henry David Thoreau illustrated their appreciation for old-growth forests in a number of popular books and inspired many others through their writing. In a 1942 essay to conserve the Porcupine Mountains (MI) Aldo Leopold writes "There will be an end to the best schoolroom for foresters to learn what remains to be learned about hardwood forestry. We know little, and we understand only part of what we know" (Flader and Callicott 1991). People from diverse cultures and religions hold old-growth forest sacred. For ethical reasons, some people inherently consider old-growth forest worthy of preservation, regardless of any "use" they may provide. For example, many people consider old-growth forest as worthy of preservation in its own right as a phenomenon of planet earth; we do not have a moral right to eliminate it (Juday 1988).

Literature Cited

Amaranthus, J.H., G.D. Klappstein, and I.G.W. Corns. 1996. Field guide to ecosites of southwest Alberta. Northern Forestry Centre, Edmonton, AB.

Barnes, B.V. 1989. Old-growth Forests of the Lake States: A Landscape Ecosystem Perspective. Nat. Areas. J. 9 (1): 45 – 57.

Borman, F.H. and G.E. Likens. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York. 253 pp.

Canadian Parks and Wilderness Society. 2001. Ecotourism Fact Sheet No. 1. Canadian Parks and Wilderness Society, Wildlands League, Toronto, Ontario

Davis, M. B. 1996. Eastern Old-growth Forest: Perspectives for rediscovery and recovery. Island Press, Washington D.C. 383 pp.

DeGraaf, R.M. and D.D. Rudis. 1987. New England Wildlife: habitat, natural history and distribution. Genl. Tech. Rep. NE-108. Broomall, PA.

Flader, S. L. and J. B. Callicott. 1991. The River of the Mother of God and other essays by Aldo Leopold. University of Wisconsin Press. Madison, WI.

Juday, G. P. 1988. Old-growth forests and natural areas: an introduction. Nat. Areas J. 8(1): 3-6.

Matlock, G.R. 1994. Plant species migration in a mixed-history forest landscape in Eastern North America. Eco. 75 (5): 1491-1502.

Meier, A.J., S. P. Bratton, and D.C. Duffy. 1995. Possible mechanisms for loss of vernal-herb diversity in logged eastern deciduous forest. Eco. App. Vol. 5 (4) pg. 935-946.

Swetnam T.W. and P.M. Brown. 1992. Oldest known conifers in the southwestern United States: temporal and spatial patterns of maximum age. In: Old-growth forests in the Southwest and Rocky Mountain Regions, Proc. of a workshop, Portal, AZ, USDA General Tech. Rep. RM-213. Pp 24-38.

Timoney K.P. and A.L. Robinson. 1996. Old-growth white spruce and balsam poplar forerts of the Peace River Lowlands, Wood Buffalo National Park, Canada. For. Eco. & Mgmt 93:101-120.

Tyrvainen, L., H. Silvennoinen, and I. Nousiainen. 2005 in press. Combining Forestry and Nature-Based Tourism in Finland: An Analysis of Development Potentials and Constraints. Scandinavian Jour. of Hospitality and Tourism Res.

U.S. Environmental Protection Agency. 2004. Nature-based Tourism. Environmental Protection Agency Issue Brief No.1, Office of Sustainable Ecosystems and Communities, U.S. Environmental Protection Agency, Washington D.C.

Wallis, C., W. Smith, and C. Wershler. 1994. An overview of wetland, old-growth and riparian avian resources in Lakeland Provincial Park Recreation Area. Alberta Parks Services, Alberta Environmental Protection, Lac La Biche, AB.

Whitney, G.C. 1987. Some Reflections on the value of old-growth forests, scientific and otherwise. Nat. Areas J. 7(3): 92-99.

Wisconsin Department of Natural Resources. 1995. Wisconsin's biodiversity as a management issue. State of Wisconsin, Dept. of Natl. Resour., Pub-RS-915

Wisconsin Department of Natural Resources. 1999. Wisconsin Statewide Comprehensive Outdoor Recreation Plan (SCORP) 2000-2005. State of Wisconsin, Dept. of Nat. Resour. Pub-PR-448 99

Wisconsin Department of Natural Resources. 2004. Wisconsin Statewide Forest Plan. State of Wisconsin, Dept. of Nat. Resour. Pub-FR-299-2004

Wisconsin Department of Tourism. 2005. Tourism's Economic Impact. State of Wisconsin, Dept. of Tourism Brochure, Madison, WI

CHAPTER 2

WISCONSIN DNR DEFINITIONS OF OLD-GROWTH AND OLD FORESTS

Perspectives concerning old growth and old forest management strategies are diverse. Old growth characteristics and potentials are extremely variable across geographic regions and ecosystems. In the Lake States, the Minnesota DNR, the Michigan DNR, and the Forest Service (USFS) have developed old growth policies. The Wisconsin DNR offers some guidelines relative to the management of old forests and old-growth in several documents, such as Big Tree Silviculture in the Silviculture Handbook (1990), the Biodiversity Report (1995), Ecological Landscapes Handbook (2002), the Statewide Forest Plan (2004), and in some State Forest Master Plans. This handbook is intended to provide definitions and comprehensive management guidelines for WDNR managed properties.

Background

For the values listed in Chapter 1 and the expectations of society, the old-growth and old forest issue needs to be addressed. Even without a precise definition, the term old-growth is perceived as an important developmental stage in our understanding of forests. Old-growth identifies a range of forest types and habitats that resource mangers are trying to accommodate for scientific, ecological, historical, and aesthetic reasons. Old forest identifies areas that can provide some or many, but not all of the old growth characteristics expected for a site.

The difficulty in formulating precise definitions of these terms is exacerbated by a forest's long slow transition. Resource managers cannot identify a specific point in time when a forest transitions into a something we all call old-growth from something we all agree is not. Similarly, from an ecological standpoint, differences between a 119-year old white pine stand and a 121-year old stand are imperceivable, even though one may be classified as old-growth through some artificial designation of a specific age. Even so, this lack of specificity does not mean we should dismiss old-growth.

Hundreds of definitions are in place for old-growth with each definition having its strengths and weaknesses. An all-encompassing definition is difficult to develop because of the following (Tyrrell et al. 1998, Kennard 2004):

- Lack of consensus as to which forest types occur in an old-growth condition,
- Difficulty in choosing which attributes to use to characterize old-growth,
- The variation that exists in species stature and spacing due to site conditions and elevation,
- Lack of available data about historic old-growth forests,
- Questionable representativeness of remnant old-growth examples,
- Changes in forest structure due to altered disturbance patterns since European settlement,
- Influences of pollution, exotics, fragmentation, and species extinction,
- The need to move beyond the stand-level treatment to consider landscape,
- Differences in forest characteristics due to geographic location,
- Differences in land use history,
- Differences in values attributed to old-growth forests,
- Altered disturbance regimes over the last 400 years have changed the bioclimatic background within which historical old-growth forest developed and may inhibit our ability to recreate that exact type of old-growth forest,
- Multiple government agencies, and non-government interest groups contending for a definition of old-growth forests favorable to their own agendas, which leads to different, conflicting, and unclear laws and regulations.
- And the political sensitivity and potential impact of any particular definition of old-growth.

Definition

The general definition for old-growth, as developed by the Wisconsin DNR is a forest that is "**relatively old and relatively undisturbed by humans."** This definition is very similar to those proposed by Hunter and White (1997) and Tyrrell (1998). To further clarify, each forest type has characteristics of forest structure and development determined by historic and current patterns of human and natural disturbance.

Many aspects of old-growth combine to equal relatively old and relatively undisturbed. Numerous conceptual ecological definitions, based on ecological processes without age thresholds, and more operational field definitions, which rely on age and other physical characteristics that can be mapped and measured, are many times seemingly in conflict. However, both are ultimately needed and necessary (Frelich and Reich, 2003). We need to connect both in a broad, multi-level definition.

To further an understanding of the multi-levels of an old-growth definition, it is valuable to have a relational basis for comparison. Such a basis can be attained by looking at the stages of stand development (after Frelich 2002). All stands have a directional change in stand structure as time progresses after disturbance. (Stage 1) Initiation lasts from the time of catastrophic disturbance until a new tree canopy is formed. (Stage 2) Stem exclusion where the forest is even-aged and dense enough to prevent new saplings from entering the canopy. (Stage 3) Transition occurs when a stand goes from one cohort of trees in canopy to more than one. There may be a wave of mortality when many trees reach senescence at the same time. (Stage 4) Muliti-aged is the point where transition to uneven-aged status is complete, where the forest has many age classes and size classes in the canopy.

Within the context of relatively old and relatively undisturbed by humans, the next level of a definition needs to consider several variables.

- Composition/Succession Variables
  - Presence of plant and animal species potentially dependent upon old-growth, such as fungi and lichens.
  - Successional stage and the representation of late successional tree species that establish in the understory and reach the canopy in tree fall gaps.
  - Species longevity; using tree age as the sole variable of the definition can misrepresent old ecosystems. Short-lived species can undergo continuous gap-phase replacement for centuries, which poses a conundrum of an old stand composed of short-lived species. Spruce budworm kills balsam fir between 40 and 50 years. Yet there are always non-infested trees of multiple ages coming up. The stands are old, and multi-aged, but do not have old long-lived trees.

- Structural Development
  - An abundance of large, old trees, recognizable by asymmetrical shapes, relatively long trunks, deeply furrowed or plated bark, signs of heartwood decay, large prominent root structures, flattened crowns with protruding dead limbs, large thick limbs, and trunks often showing a twist that develops with age.
  - Wide variation in tree sizes and spacing that reflect years of small natural disturbances.
  - Diverse vertical structure that includes multiple layers, each reflecting a broad spectrum of ages: overstory trees, understory trees, shrub, herbaceous and ground layers.
  - Forests occur as a gradient of growth forms from dwarf to tall, small to large diameter, and gnarly to straight. Soil depth and texture, and water and nutrient supply, can affect height. Dwarf forests on poor sites can also undergo the same gap-replacement process, as that occurring on rich sites.
  - Large volumes of coarse woody debris and standing snags representing a wide variety of decay classes.
  - Tree-fall gaps of various sizes and ages.
  - Undulating forest floor expressed in randomly scattered pits and mounds.

- Functional Variables
  - Natural disturbance regimes influence species presence
  - Long-term steady state influences nutrient cycles
  - Undisturbed soils. Soil macropores, thick humus layers.
  - Little evidence of disturbance by humans
  - Evidence of fire scarring in fire shaped systems (especially red pine and oaks)

- Landscape/Disturbance Variables
  - Old forests are not static and disturbance affects these stands. In ecosystems that experience more frequent disturbances, such as fire-shaped ecosystems, old-growth patches may develop due to topographic position or chance. These patches may not be permanent at an exact place in the landscape, but they are always present some place on the landscape. They shift over centuries or millennia.
  - Shifting mosaic steady state in northern hardwoods and hemlock/hardwoods

Old-growth forests are not decadent, over-mature, stagnant or unproductive ecosystems. They are dynamic places that exhibit continuous activity. Old-growth forests are often misrepresented as only containing large impressive trees. It is far easier for people to recognize and protect large, impressive old trees than it is for them to understand that dwarf forests, like slow growing bog forests, can have old-growth forest attributes worthy of consideration.

WDNR Classes Of Old-growth And Old Forest

Three ecological classes and four management classes of relatively old forest are conceptually and operationally defined. Stand level evaluations are emphasized, but a landscape perspective is maintained. In order to maintain definitions as simple and useful as possible, only a limited number of criteria are emphasized, including disturbance history, age and age structure, and commitment to specified forest management goals.

The three ecological classes are defined based on disturbance history, age thresholds, and structural thresholds. Important considerations include developmental and successional stages, compositional and structural attributes, and site variability. Ecological classes:

- Relict Forest (includes Relict Old-growth Forest)
- Old-growth Forest
- Old Forest

The four management classes are defined based on long-term management goals and commitments. Each class has different management limitations. For any given stand or landscape, the potential commitment to different management goals and limitations would result in the long-term development of distinctive forest conditions. Management classes:

- Reserved
- Managed
- Extended Rotation (includes Big Tree Silviculture)
- Uncertain Management

The following section provides conceptual definitions. In practice, for a given stand or landscape, the ecological and management classes would be combined to describe current condition, developmental expectations, and management commitments and limitations. Within the cover type chapters, operational definitions for designating classes, ecological characterization of ecological classes, and management considerations for management classes are further refined.

Ecological classes

Relict forest (aka primary, virgin, ancient, or natural heritage forest)

Relict stands or landscapes appear never to have been manipulated, exploited, or severely disturbed by humans of European origin; in Wisconsin, the stand and site should show no evidence of significant human disturbance since about 1800 AD. These forests have a continuous heritage of natural disturbance and regeneration, although indirect human impacts may have resulted in ecological modification (e.g. fire suppression, increased herbivory, atmospheric deposition). In essence, some pre-European settlement, forest ecosystem conditions have been perpetuated. Native forest plants, which were established through natural regeneration, dominate. Stands of any age, developmental stage, or successional stage may be included. The subcategory **relict old-growth forest** is both relict and old-growth, containing some old, biologically mature trees. The specific disturbance criteria for relict forests will limit examples to only a few small representative stands in Wisconsin.

Old-growth forest

Old-growth forests are relatively old and relatively undisturbed by humans. Old-growth stands are biologically old, containing some trees which are nearing or beyond their average expected lifespan. The original even-aged overstory, established following a catastrophic disturbance, is becoming senescent, is senescing, or has senesced. Typically, the development of old-growth conditions begins near the end of the stem exclusion stage; the most characteristic stages of stand development are demographic transition and multi-aged. Specific historic human disturbance events are relatively unimportant, as long as age and developmental criteria are met. The actual qualifying stand age will vary depending on dominant species (forest type) and site capability. Old-growth forests are dominated by native vegetation.

The Biodiversity Report (WDNR 1995) defines old-growth as 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.

Old forest

Old forest stands are older than the typical managed forest, but are not biologically old. They are beyond economic maturity, but are not senescent. These stands are older than their traditional rotation age [usually near the age where mean annual increment (MAI) is at a maximum]. Typically, old forest stands are still in the stem exclusion stage of stand development, but, depending on forest type and disturbance history, they can be in the transition or multi-aged stages. Historic human disturbance is unimportant, as long as age and developmental criteria are met. The actual qualifying stand age will vary depending on dominant species (forest type) and site capability. Old forests are dominated by native vegetation.

Management classes

Reserved

Reserved stands and landscapes are dominated by relict, old-growth, or old forests (ecological classes). They should have the basic ecological integrity of stand composition, stand development stage, and structural potential that indicates a high probability for recovery in the not too distant future. The primary management goal is the long-term maintenance of relict forest or the development and maintenance of old-growth compositional, structural, and functional attributes within a minimally manipulated environment. Future active management is very limited. Some general potentially allowable management activities are:

- fire presuppression and suppression,
- prescribed fire,
- pest control (e.g. exotic organisms and herbivores),
- recreation management, and
- research activities.

Specific allowable management activities and limits are described in the cover-type chapters.

Managed

Managed stands and landscapes are dominated by old-growth or old forests (ecological classes). They should have the basic ecological integrity of stand composition, stand development stage, and structural potential that indicates a high probability for recovery in the not too distant future. The primary management goal is the long-term development and maintenance of some old-growth or old forest ecological attributes within environments where limited management practices and product extraction are allowed. Tree cutting can be applied to enhance or accelerate the development of old-growth compositional, structural, and functional attributes. Silvicultural applications may be needed in the case of mid-tolerant species, such as white pine and red oak, to regenerate and maintain the type. When trees are cut to achieve management objectives, some timber harvesting is acceptable. Some general potentially allowable management activities are:

- manipulation of reproduction,
- acceleration or enhancement of compositional, structural, or functional development,
- limited timber harvest and salvage operations,

- simulation of natural processes,
- fire presuppression and suppression,
- prescribed fire,
- pest control (e.g. exotic organisms and herbivores),
- recreation management, and
- research activities.

Specific allowable management activities and limits are described in the cover-type discussions.

Extended rotation

Extended rotation stands and landscapes are dominated by old forests (ecological class). These mature stands are dominated by trees older than their traditional rotation age, yet younger than their pathological rotation age (average life expectancy). Extended rotation forests are managed for both commodity production and the development of some ecological and social benefits associated with older forests. The development of a variety of structural, compositional, and functional attributes common to older forests is encouraged. These forests can be even-aged or uneven-aged. **Big tree silviculture**, an existing WDNR policy, is a specific subcategory, which addresses aesthetic and recreational attributes of extended rotation forests.

Uncertain management

This management class can be assigned to any of the ecological classes (relict, old-growth, and old forests), when and where future management is uncertain (no known long-term management commitment). Many old forests on private nonindustrial forest lands may be represented by this class.

Application

Combining Ecological and Management Classes

Three ecological classes and four management classes of relatively old forest have been defined.

In practice, for a given stand or landscape, the ecological and management classes would be combined (Tables 2-1 and 2-2). The ecological class assigned will describe current condition (either disturbance history or age structure). The management class assigned will describe developmental expectations, and management commitments and limitations. Specific operational definitions for stand designation are presented in each cover type chapter. For each designated stand, it would be useful to identify and describe current composition and expected successional change, current structure and expected structural development, and disturbance history and expected future disturbance regime.

Change Over time

Depending on management activities and environmental variables, the ecological class may change over time as a forest develops or is disturbed. As young forests develop and mature they can become old forests. Old forests can develop into old-growth forests. This developmental change can be planned for and could result in changes in designation. For example, as a forest ages and develops structurally, an old forest-managed could become an old-growth forest-managed or reserved. Also, forests can change in composition, so an old-growth-reserved oak forest could become an old-growth-reserved northern hardwood forest.

Disturbance can convert old-growth or old forests to younger forests. A stand may not meet the age requirement, but may still be considered old-growth or old forest, if it was previously so designated, will continue to be so designated, and the disturbance which modified age class structure was of natural (non-human) origin or was human induced to simulate natural disturbance (management class guidelines must be adhered to). Otherwise, if direct human disturbance causes a reduction in age structure to below designation thresholds, then the ecological class will need to be re-evaluated. For example, even-aged old forests managed under extended rotation can eventually be harvested and regenerated to young forests.

Landscape Management

Both stand and landscape level evaluations are needed. Designation depends on stand characteristics, but management is best implemented in a landscape context. Designated old-growth or old forest landscapes may contain some individual stands which do not meet the stand-based age requirement. Mature forested landscapes could be expected to exhibit heterogeneous patterns of stand age distribution, potentially including some younger stands.

Minimum Stand Size

WDNR recon protocol identifies two acres as a minimum stand size. For operational reasons, the minimum size for an old forest or old-growth stand is also two acres. However, smaller patches and even individual old trees can be recognized and maintained to provide specific desired benefits. In general, larger stands and landscapes will provide increased old forest and old-growth benefits. Larger areas and repetition in representation can buffer the effects of uncontrolled disturbance events.

Potential Future Old Forests and Old-growth

Forest management plans can identify stands and landscapes as desired future old forest or old-growth even though current age structure does not meet the necessary thresholds. Younger forests can develop into old forests, and eventually these can become old-growth forests. A variety of management techniques, ranging from very active to passive, can be applied in the meantime, until ecological thresholds are reached and management commitments are made. Management in the interim could encourage the development of cover type specific compositional and structural attributes characteristic of old forests. Property management plans should identify desired future conditions and interim management objectives.

Compatibility with Master Planning Land Management Classification System

Section NR 44.05, Wis. Adm. Code, details the land management classification system used in developing, revising, and amending master plans for Department managed properties. The system is used to describe the general management objective for a property or a management area within a property as determined during the master planning process. This process may identify specific areas to be managed for old forest or old-growth (as defined herein). The land management classes applied to these areas should be those that best coincide with the specific management objectives. Table 2-3 identifies which of the seven land management classes best describe the management commitment prescribed by each of the three old-growth and old forest management classes that could be applied on Department managed properties. Although these best fits are identified, small areas of relatively old forest could be managed as inclusions within most other land management classes. The best fit for Extended Rotation is Forest Production, for Managed (old forest or old-growth) it is Native Community, and for Reserved (old forest, old-growth, or relict) the best fit could be either Native Community or Wild Resources Management Areas.

Further Detail

The cover type chapters provide specific information needed to evaluate, characterize, designate, and manage stands. Some specific landscape considerations are also described. The Landscape Management Considerations chapter provides guidance on evaluating and managing landscapes.

Table 2-1. Compatibility of ecological and management classes ("+" signifies compatibility)

Management Classes	Ecological Classes		
	Relict Forest	Old-growth Forest	Old Forest
Reserved	+	+	+
Managed		+	+
Extended Rotation			+
Uncertain Management	+	+	+

Table 2-2. Comparison of defining criteria among old-growth and old forest combined ecological-management classes (uncertain management class not included).

Defining Criteria	Relict – Reserved	Old-growth – Reserved	Old-growth – Managed	Old Forest – Reserved	Old Forest – Managed	Old Forest – Extended Rotation
Minimum Age[1]	none	near average life expectancy	near average life expectancy	Max. MAI[2]	Max. MAI[2]	Max. MAI[2]
Maximum Age	none	none	none	near average life expectancy	near average life expectancy	near average life expectancy
Human Disturbance History	none	any	any	any	any	any
Management Commitment Required	yes	yes	yes	yes	yes	no
Active Management	none to very limited	none to very limited	limited	none to very limited	limited	few limits
Timber Production	none	none	limited	none	limited	few limits
Developmental Stage	any	mostly transition and multi-aged	mostly transition and multi-aged	mostly stem exclusion	mostly stem exclusion	mostly stem exclusion

[1] Exceptions for natural disturbances within designated stands, and stands within designated landscapes.
[2] MAI = Mean Annual Increment, which is used to determine rotation ages.

Table 2-3. Compatibility of old-growth and old forest management classes with master planning land management classification system (s. NR 44.05, Wis. Adm. Code)

Master Plan Land Management Areas	Old-growth and Old Forest Management Classes		
	Reserved	Managed	Extended Rotation
Forest Production	Could Occur	Could Occur	**Best Fit**
Habitat	Could Occur	Could Occur	Could Occur
Native Community	**Best Fit**	**Best Fit**	Could Occur
Special	Could Occur	Could Occur	Could Occur
Recreation	Could Occur	Could Occur	Could Occur
Scenic Resources	Could Occur	Could Occur	Could Occur
Wild Resources	**Best Fit**	Cannot Co-occur	Cannot Co-occur

Literature Cited

Frelich, L. E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forest. J. For. 102 (3):22-28

Frelich, L.E. and P.B. Reich. 2003. Perspectives on development of definitions and values related to old-growth forests. Environ. Rev. 11:S9-S22.

Hunter, M.L., Jr. and A.S. White. 1997. Ecological thresholds and the definition of old-growth forest stands. Nat. Areas J. 17(4): 292-296.

Kennard, D.K. 2004. Forest Encyclopedia Network. Southern Region Extension Forestry. Athens, GA

Tyrrell, L.E., G.J. Nowacki, T.R. Crow, D.S. Buckley, E.A. Nauertz, J.N. Niese, J.L. Rollinger, and J.C. Zasada. 1998. Information about old growth for selected forest type groups in the Eastern United States. USDA, Forest Service, Gen. Tech. Rep. NC-197. 507 pp.

Wisconsin Department of Natural Resources. 1990 (2004). Silviculture Handbook. State of Wisconsin, Dept. of Natl. Resour. Hndbk. 2431.5

Wisconsin Department of Natural Resources. 1995. Wisconsin's biodiversity as a management issue. State of Wisconsin, Dept. of Natl. Resour. Pub-RS-915

Wisconsin Department of Natural Resources. 2002. Wisconsin Ecological Landscapes Handbook. State of Wisconsin, Dept. of Natl. Resour. Hndbk. 1805.1

Wisconsin Department of Natural Resources. 2004. Wisconsin Statewide Forest Plan. State of Wisconsin, Dept. of Natl. Resour. Pub-FR-299-2004

CHAPTER 10

INTRODUCTION TO FOREST COVER TYPES AND REVIEW OF FOREST DYNAMICS

In Chapter 2, a general conceptual definition of old-growth is adopted. Also, conceptual definitions of three ecological classes and four management classes of relatively old forests are presented. Within the following chapters, organized by forest cover types, Hunter's (1989) suggestion to develop specific operational definitions for each forest type taking into account forest composition and structure, forest dynamics, and historical and current patterns of natural and human disturbance is implemented.

Each chapter is based on forest cover types as defined in the WDNR Silviculture Handbook (WDNR 1990). Some cover types have been combined if they share similar ecological traits and frequently co-occur. Emphasis has been placed on commonly occurring, relatively long-lived, late to mid-successional types. These types offer the greatest opportunity to satisfy large-scale management goals associated with old forests and old-growth. The availability of information detailing ecological characteristics and potential management techniques is highly variable among cover types and geographical regions, and is reflected in the unequal specificity of information provided in each chapter. When available, local and regional information has been preferentially utilized. Forest cover types can be cross-referenced with other terrestrial vegetation classification systems used by the WDNR, specifically the Wisconsin Natural Heritage Inventory and the Forest Habitat Type Classification System.

Within each chapter, each forest cover type is defined and described. Operational criteria (*i.e.* thresholds) for identifying and designating the ecological classes; relict forests, old-growth forests, and old forests; are provided. For each class, relevant ecological concepts and characteristics are further detailed. Management considerations and operational limitations are refined for each management class; reserved, managed, and extended rotation forests. In addition, ecological concepts and management considerations for forested landscapes are presented. Finally, some lists identifying specific representative stands and landscapes are offered, and literature is referenced.

Forest Dynamics

Forest communities and ecosystems are dynamic; they change continuously in space and time (Spurr and Barnes 1980). However, the rate and severity of change are variable both within and between communities and ecosystems. Although dynamic, periods of relative stability and instability occur.

When examined in detail, each community and ecosystem is unique. Uniqueness is expressed in composition and structure, and also function and development. Even so, communities and ecosystems can be classified and described based on relative similarities and differences. Major processes that guide forest stand dynamics also can be classified and described, and include disturbance, succession, and structural development. Classification and characterization can facilitate interpretation of natural systems and potential responses to disturbance (including management) and environmental change.

Disturbance

In forest ecosystems, disturbance is any relatively discrete event in time that disrupts structure, and changes resources, substrate availability, or the physical environment (Helms 1998). Disturbance is an integral part of ecosystem dynamics. It affects stand development and succession, and is a major determinant of forest stand and landscape composition, structure, and function (Borman and Likens 1979). Some level of disturbance impacts all forest communities over time (Spurr and Barnes 1980). Parameters used to describe and classify disturbance are type, severity, timing, and spatial pattern.

The interaction of disturbance type, severity, and timing results in a variety of disturbance regimes, patterns, and potential forest stand and landscape impacts. Most agents of disturbance occur on a continuum (e.g. breezes to hurricanes and frequent to rare). The severity of single disturbance events can range from light, to moderate, to catastrophic impacts on stand structure. The timing of events refers to the frequency and regularity of events (*e.g.* individual fire versus successive fires), and interactions among different types of disturbance (*e.g*. blowdown followed by fire). Different tree species and forest community types are adapted to reproduce and thrive with different disturbance regimes. Lorimer (2001) identifies five guiding principles relative to the interpretation of disturbance regimes:

- "Evidence of natural and anthropogenic disturbance is not disentangled easily."
- "Disturbance regimes vary over time."

- "Disturbance patterns on the landscape are spatially nonrandom."
- "Severe disturbance is highly episodic and spatially heterogeneous."
- "Many severe disturbances do not initiate forest succession."

Many types of forest disturbance originate from external causes. Typical external (exogenous) forces are fire, weather events, and tree cutting. These forces not only hasten the death of weakened trees, but also damage or kill relatively vigorous trees. Another kind of disturbance is caused by internal (endogenous) factors, and results in the localized fall of individual trees that have been weakened or killed during the process of growth and development. At light levels of severity, external forces interact with and are difficult to separate from internal factors (Borman and Likens 1979).

Types of natural disturbance include: fire, weather events (*e.g*. wind, snow, ice, hail, flooding, drought), insects and diseases, and herbivory. Historically, fire was an important type of natural disturbance in Wisconsin, however Native Americans did play a role in initiating many fire events. Fire was particularly prevalent in southern Wisconsin (specifically Province 222, south of the tension zone) and on sandy outwash in the north (Appendix A, Fig A.2). It had significant regional impacts on ecosystem dynamics. Fire can alter ecosystem composition, structure, and function. It can impact forest regeneration, competition and succession, stand structural development, biomass accumulation, soil development, the potential occurrence of other types of disturbance, and wildlife dynamics. Modern fire protection has reduced the severity and altered the pattern of fires to such a great extent that broad ecological impacts of fire have become nearly irrelevant.

Catastrophic wind disturbance was locally infrequent yet regionally significant in northern Wisconsin (Canham and Loucks 1984). Storms causing moderate to light severity disturbance were common (Frelich and Lorimer 1991). The impacts of wind disturbance on forest composition ranged from minor to moderate, enabling release and gap replacement, whereas impacts on structural development were proportional to the severity of the disturbance. Although intense storms were more frequent in southern Wisconsin, historical wind events causing blowdowns were much less pervasive due to the lesser representation of extensive, closed, mature to old forests. Wind events continue to impact Wisconsin forests, but younger forests are more resistant to light to moderate severity disturbance, and weather patterns are changing.

Human caused disturbance has become the predominant type of disturbance impacting forests in Wisconsin (Stearns 1986). It is a major determinant of forest stand and landscape composition, structure, and function. Types of human disturbance include: land use conversion, alteration of drainage patterns, fire management (control and prescription), forest management (especially logging), hunting, recreation, and introduction and control of exotic species. *Land use decisions are critical in determining the distribution of forests and their landscape context. Forest management decisions are critical in determining forest composition and structure. Together, these decisions have significant impacts on ecosystem function.* Emerging issues relative to forest disturbance and environmental change include: deer management and herbivory, invasive exotic species, endangered species and extinction, maintenance of ecological diversity, and climate change.

Human disturbed forest ecosystems develop differently than do "naturally" (without humans) disturbed ecosystems. However, "many ecologists believe that conservation of biological diversity in forests will require management plans that mimic to some extent the long-term historical and natural disturbance regime. The rationale is that management practices need to provide a similar mix of habitat conditions to which various organisms have become adapted to ensure their long-term survival" (Lorimer 2001).

Succession

Succession is the gradual replacement of one plant community (*i.e*. species composition) by another (Spurr and Barnes 1980, Helms 1998, Frelich and Reich 2003). As succession progresses, disturbances can modify successional direction. Secondary succession in forest ecosystems is initiated by catastrophic disturbance.

As succession advances, forest community composition often is a progressive continuum through time. Therefore, the recognition of distinct stages of succession is an abstract construct. However, classifying successional stages and processes, and modeling potential successional pathways are useful constructs that can aid understanding of forest dynamics and potentials (Spurr and Barnes 1980). The incorporation of variable disturbance regimes increases complexity.

Three basic conceptual models of successional processes are relay floristics, gap phase replacement, and release (Spurr and Barnes 1980, Kotar 1997).

- Relay floristics is a model of complete compositional change where more shade tolerant species grow into the overstory and gradually replace the less tolerant species that dominated the former overstory.
- Gap phase replacement is a model of partial compositional change where midtolerant species are able to quickly colonize an opening and then outgrow their competitors. Canopy gaps may result from senescence or light exogenous disturbance, and are captured through regeneration.
- Release is another successional model, similar to gap phase replacement, but gaps are captured through the liberation of persistent advanced regeneration or suppressed trees of shade tolerant species. In stands dominated by shade tolerant, late-successional species, the changes in species composition may become relatively minor. These stands may be considered relatively stable compositionally, at least until disturbances alter understory composition and overstory recruitment.

Additionally, there are many other models, both conceptual and quantitative, developed to describe successional processes and potentials.

The process of forest succession, under specified site conditions and barring significant exogenous disturbance, will eventually lead to the formation of a relatively stable type of forest community, typically characterized by relatively shade tolerant and long-lived tree species (Graham 1941, Spurr and Barnes 1980, Stearns 1986). Conceptually, a climax forest is a relatively stable and long-lived community that develops late in the course of vegetation development on a specific site. However, even these late-successional communities continue to change, but change proceeds at a more gradual rate (Spurr and Barnes 1980, Kotar 1997).

Disturbance processes may or may not alter successional patterns (Lorimer 2001, Frelich 2002). The degree of impact depends on such factors as overstory composition, understory composition, regeneration strategies of local species, and the type, severity, and timing of disturbances. In some cases, moderate to severe disturbances do not initiate forest succession (*e.g*. blowdown of northern hardwoods with release of advance regeneration, or a single crown fire in jack pine), while in other cases such disturbances can result in abrupt compositional change (*e.g*. a single crown fire in northern hardwoods, or blowdown of jack pine). Likewise, moderate to light severity disturbances may or may not influence species composition and successional dynamics. Also, site conditions can impact disturbance processes and successional patterns. Some disturbance regimes can periodically curtail succession, and thus preclude the development of relatively stable communities (Graham 1941, Spurr and Barnes 1980).

<u>Stand Structural Development</u>

Stand development is the gradual directional change in stand structure over time (Helms 1998, Frelich and Reich 2003). As development progresses, disturbances will modify structural conditions. Catastrophic disturbance will reinitiate stand structural development. Significant successional changes may or may not accompany major developmental changes.

In general, forest stand development is a continuum in time. Therefore, the recognition of stages of development is an abstract construct. However, modeling development is useful to aid understanding of forest dynamics and potentials.

The basic conceptual models of stand structural development begin following a catastrophic, canopy-leveling disturbance and proceed until another such disturbance reinitiates the developmental sequence. The complete developmental sequence is defined in the absence of significant (*i.e*. moderate to catastrophic severity) disturbance. The incorporation of variable disturbance regimes increases conceptual complexity of developmental models.

Detailed discussions of stand developmental processes are offered by: Borman and Likens 1979, Oliver and Larson 1990, Franklin *et al*. 2002, and Frelich 2002. Although the processes described are similar, the delineation and interpretation of stages of development are somewhat different. Following is a summary of the four basic stages of development, following Frelich 2002. The duration of each stage is dependent on site factors, species composition, and interpretation of definitions and concepts.

Initiation: The initiation of stand development begins following a catastrophic disturbance. The temporary open space will become occupied by tree reproduction as the forest ecosystem reorganizes. Tree species composition may be very similar to the previous stand (*e.g.* blowdown that releases advanced regeneration) or quite different (*e.g.* intense fire followed by colonization by light seeded intolerant species). This stage lasts for relatively few years (typically 3-30 years), and ends when the canopy becomes continuous and trees begin to compete with each other for light and canopy space.

Stem exclusion: This stage is characterized by an even-aged forest with a generally uniform canopy. The major cause of tree mortality within the stand is density dependent self-thinning. This competition among trees for growing space tends to eliminate smaller crowned and suppressed trees. The resulting small canopy gaps are usually filled by the growth of the crowns of vigorous overstory trees. In general, canopy gaps are small and close quickly, thus precluding the ascension of new cohorts into the canopy. The intense competition and mortality among canopy trees results in increasingly fewer and larger trees over time. Bormann and Likens (1979) hypothesized that the greatest total accumulation of stand biomass is achieved near the end of this stage.

Demographic transition: This stage is characterized by the onset of significant mortality among dominant, large-crowned canopy trees, creating abundant and relatively large canopy gaps that are too wide to be filled by crown expansion of the older trees comprising the original cohort. Mortality is largely caused by processes related to tree senescence or by light severity exogenous disturbance. There are two potential processes by which younger trees can eventually fill these large gaps: 1) the release of suppressed relatively tolerant trees that have previously regenerated and persisted in the shade of the understory, or 2) the regeneration and growth of trees within the gap. These dynamics result in the transition from a relatively even-aged to an uneven-aged condition, with increasing horizontal and vertical diversity. Changes in species composition may or may not occur. Although tree mortality results in the accumulation of standing and downed coarse woody debris, Bormann and Likens (1979) hypothesized that total biomass is declining, because a stand dominated by relatively old and large trees is being replaced by a stand dominated by a patchy mixture of tree ages and sizes.

Multi-aged: At this stage the stand is uneven-aged and the original post-disturbance even-aged cohort has been essentially eliminated. The uneven-aged forest is now composed of patches of trees of varying size and age. Canopy gap dynamics (replacement and release) result in the regeneration and ascension of new age classes. Irregular, light severity disturbance is characteristic. Significant changes in species composition may or may not occur.

Multi-aged stands are uneven-aged. Most exhibit non-equilibrium age structures reflecting episodic recruitment of new age classes into the canopy. Unmanaged stands exhibiting an equilibrium age structure (*i.e.* reverse-J curve) are uncommon. The development of steady state conditions requires long periods free from major disturbance.

Steady state refers to a condition of a system or process that does not change in time. Forest ecosystems are dynamic and do not achieve a long-term steady state in composition and structure (Borman and Likens 1979, Spurr and Barnes 1980, Mladenoff 2000, Runkle 2000, Woods 2000). However, some forests may change relatively slowly and may temporarily exhibit equilibrium conditions (Borman and Likens 1979, Frelich 2002).

In a quasi or shifting mosaic steady state, conditions approximate a steady state and change is relatively slow. A shifting mosaic steady state stand is composed of a spatial mosaic of irregular patches (gaps) with vegetation of different ages (Borman and Likens 1979). Although individual patches cycle through changes, the proportion of different patch ages within the stand remains relatively constant over time. Stands are all-aged with an equilibrium age structure. Also, species composition and abundance within the stand remain fairly constant over time. Borman and Likens (1979) hypothesized that total biomass fluctuates about a mean. Light intensity disturbance is characteristic, but moderate or catastrophic disturbance will negate the condition. Within the Lake States, this condition was and is uncommon, but may temporarily describe some old unmanaged northern hardwood and hemlock stands (Borman and Likens 1979, Mladenoff 2000, Frelich 2002). In other forest ecosystems, quasi steady state conditions at the stand level rarely if ever occur due to relatively frequent major disturbance events (*e.g.* fire systems).

Four basic stages of stand structural development have been summarized (Figure 10.1). Frelich (1995) suggested that the transition and multi-aged stages represent old-growth. Old-growth forests typically have complex vertical and horizontal structure (Franklin and Van Pelt 2004). These later stages of development exhibit complex structural characteristics and can be difficult to differentiate based on tree age and size distributions.

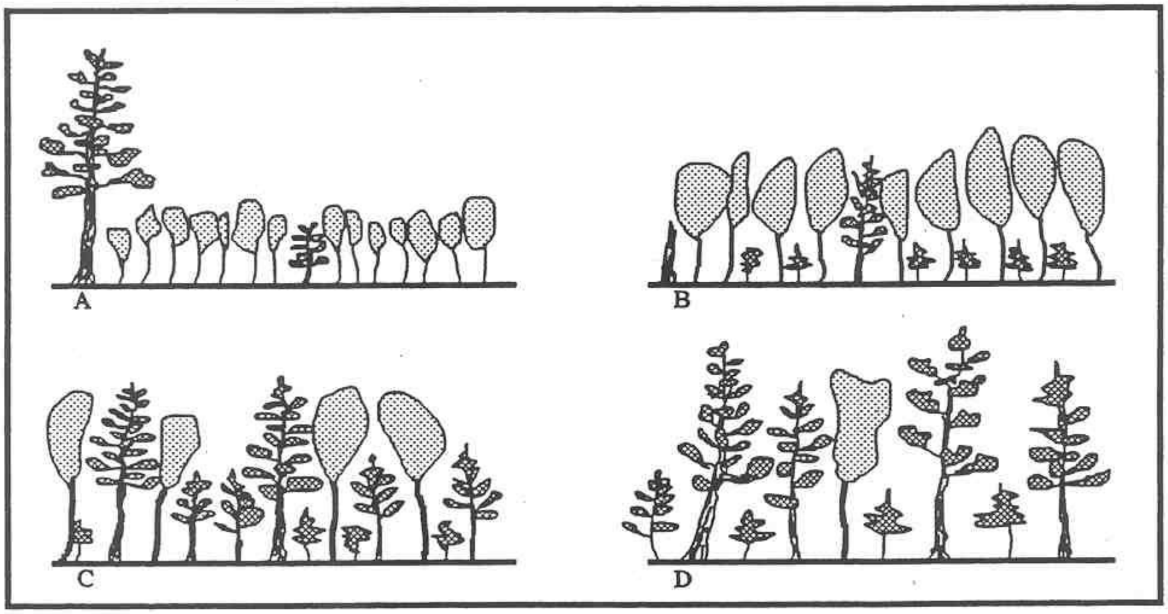


Figure 10.1. Canopy structure profiles of the four stages of stand development in an aspen-white pine forest: A. Stand initiation stage, B. Stem exclusion stage, C. Demographic transition stage, and D. Multi-aged stage (from Frelich 1992).

Quasi-equilibrium Landscapes

A quasi-equilibrium landscape exhibits an approximate balance between the forces of development (*i.e*. structural development and succession) and diminishment (*i.e.* disturbance). These landscapes may be considered relatively stable as a whole although composed of patches of instability (Borman and Likens 1979, Spurr and Barnes 1980). At the landscape scale, stability can be sustained for long periods (*e.g*. centuries to a millennium) (Frelich 2002).

The forest age-class distribution of a quasi-equilibrium landscape remains stable over time, although the location and extent of developmental patches varies (Frelich 2002). It is a mosaic of irregular patches composed of vegetation of different ages and in different stages of development, which over time shifts spatially but maintains proportional constancy. Patch development may or may not include successional change. Vegetation attributes exhibit general constancy when averaged over the entire landscape. Cumulatively, the forest landscape is uneven-aged. Disturbance is part of the system, but the disturbance regime must remain consistent. Disturbances must occur at a relatively constant rate, and disturbed patches must be small relative to the size of the landscape.

Management and Forest Dynamics

With modern human impacts, significantly changed disturbance regimes, modified environments, climate change, and uncertain future environmental conditions, future forest dynamics are uncertain and long-term quiescence is unlikely. “What is ‘natural’ vegetation in a changing environment?” (Sprugel 1991) is a question “that managers must consider whenever they use information on past conditions to establish management goals” (Lorimer 2001). However, understanding historical dynamics could help identify potential responses to future perturbations. The management of dynamic processes could enable the maintenance of ecosystem diversity and resilience. The maintenance of diverse forests, at both stand and landscape scales, could help facilitate ecological and sustainable management responses to changing environmental conditions (Stearns 1986, Mladenoff 2000).

Forest Cover Types – Summary and Comparison

The major forest cover types that could be managed to provide old forest and old-growth conditions and benefits in Wisconsin are listed in Table 10-1 and discussed in the following chapters. They are mostly commonly occurring, relatively long-lived, late to mid-successional types. These cover types offer the greatest opportunity to satisfy large-scale management goals associated with old forests and old-growth.

The relatively short-lived and least successionally stable common forest cover types (*i.e*. aspen, white birch, and jack pine) are not included in Table 10-1. These types can be managed to provide some short-term old forest benefits, but they are soon either replaced through succession or regenerated through catastrophic disturbance.

The principal ecological criterion utilized to identify old forest and old-growth is the age of the oldest overstory trees. In Table 10-1, minimum age thresholds used to identify the old forest and old-growth ecological classes for each cover type are presented and can be compared. The proportion of trees required to meet these minimums is detailed in each chapter.

Table 10-1 also presents a relative ranking of successional stability for each forest cover type. On typical sites, with relatively stable environmental conditions, and barring significant disturbance, the most stable communities are expected to change in composition very slowly. Less stable communities typically exhibit more rapid and drastic compositional change when dominant overstory trees reach old age and begin to die in significant numbers; they typically require significant disturbance to perpetuate themselves.

Table 10-1. Summary and comparison of major forest cover types, minimum age thresholds, and relative successional stability.

Forest Cover Type	Old Forest Begins (years)	Old-growth Begins (years)	Potential Successional Stability [1]
Northern Hardwood	120	170	*****
Hemlock	150	210	*****
White Pine			***
Red Pine			*
Oak			**
Central Hardwood			***
Red Maple			****
Swamp Hardwood			****
Bottomland Hardwood	110-120	130-170	***
Swamp Conifer – Cedar			*****
Swamp Conifer – Fir-Spruce-Tamarack			****
Upland Fir-Spruce			****

1: ***** most to * least, but will vary depending on site quality

Literature Cited

Borman, F.H. and G.E. Likens. 1979. Pattern and process in a forested ecosystem. Springer – Verlag, New York. 253 pp.

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65(3):803-809

Franklin, J.F. and R. Van Pelt. 2004. Spatial aspects of structural complexity in old-growth forests. J. For. 102(3):22-28

Franklin, J.F., T.A. Spies, R. Van Pelt, A.B. Carey, D.A. Thornburgh, D.R. Berg, D.B. Lindenmayer, M.E. Harmon, W.S. Keeton, D.C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir as an example. For. Ecol. and Mgmt. 155:399-423

Frelich, L.E. 1992. The relationship of natural disturbances to white pine stand development. In: White Pine Symposium Proceedings: History, Ecology, Policy, and Management. Pub. NR-BU-6044-S. Edited by R.A. Stine and M.J. Baughman. Univ. of Minn., St. Paul, MN. pp. 27-37

Frelich, L.E. 1995. Old forest in the Lake States today and before European settlement. Nat. Areas J. 15:157-167

Frelich, L.E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge, U.K.

Frelich, L.E. and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region. Ecol. Monogr. 61:145-164.

Frelich, L.E. and P.B. Reich. 2003. Perspectives on development of definitions and values related to old-growth forests. Environ. Rev. 11:S9-S22

Graham, S.A. 1941. Climax forests of the upper peninsula of Michigan. Ecology 22(4):355-362

Helms, J.A. ed. 1998. The dictionary of forestry. Society of American Foresters. 210 pp.

Hunter, M.L. 1989. What constitutes an old-growth stand? J. For. 87:33-35

Kotar, J. 1997. Approaches to ecologically based forest management on private lands. Pub. NR-604. Univ. of Minnesota Extension Service. 18 pp.

Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. Wildl. Soc. Bull. 29(2):425-439

Mladenoff, D.J. 2000. A tale of two forests: The history of the northern forest and a tribute to Forest Stearns. Sigurd Olson Env. Institute, Northland College, Ashland WI

Oliver, C.D. and B.C. Larson. 1990. Forest stand dynamics. McGraw-Hill, New York

Runkle, J.R. 2000. Canopy tree turnover in old-growth mesic forests of eastern North America. Ecology 81(2):554-567

Sprugel, D.G. 1991. Disturbance, equilibrium, and environmental variability: what is 'natural' vegetation in a changing environment? Biological Conservation 58:1-18

Spurr, S.H. and B.V. Barnes.1980. Forest ecology, third edition. John Wiley & Sons, New York. 687 pp.

Stearns, F. 1986. Ecological view of the second hardwood forest and implications for the future. In: Proceedings, the Northern Hardwood Resource: Management and Potential. Edited by G.D. Mroz and D.D. Reed. Mich. Tech. Univ., Houghton, Mich. pp. 51-66

Wisconsin Department of Natural Resources. 1990 (2004). Silviculture Handbook. State of Wisconsin, Dept. Natl. Resour. Hndbk. 2431.5

Woods, K.D. 2000. Dynamics in late-successional hemlock-hardwood forests over three decades. Ecology 81(1):110-126.

CHAPTER 11

NORTHERN HARDWOOD

DESIGNATION OF ECOLOGICAL AND MANAGEMENT CLASS

Ecological Class

To meet minimum requirements for initial designation as relict forest, old-growth forest, or old forest, northern hardwood stands must meet one of the following criteria:

A. Relict Forest
1. Past and current stands on the site apparently have not been exploited, manipulated, or severely disturbed (>10% canopy removal) by humans since about 1800 AD, based on best available information.
   a. **Relict Old-growth Forest**: both relict and old-growth, meeting conditions detailed in both "A" and "B".
   b.

B. Old-growth Forest
1. Even-aged/two-aged; at least 20% of stand basal area comprised of trees at least 170 years old, or
2. Uneven-aged; contains at least 80 square feet per acre of basal area in trees 5 inches DBH (diameter at breast height) and greater, 50% of stand basal area in trees 18 inches DBH and greater, and 1 tree per acre greater than 24 inches DBH.
3.

C. Old Forest
1. Even-aged/two-aged; at least 20% of stand basal area comprised of trees at least 120 years old, or
2. Uneven-aged; contains at least 80 square feet per acre of basal area in trees 5 inches DBH and greater, 33 square feet per acre in trees 18 inches DBH and greater, and 12 square feet per acre in trees 22 inches DBH and greater.

Management Class

Once the ecological class is determined, the management goals and commitments will determine the designation of the appropriate management class: **reserved**, **managed**, **extended rotation**, or **uncertain management**. Each management class is defined by distinctive management goals, commitments, and limitations. Therefore, once designated, the different management regimes are expected to result in the development of distinctive forest conditions.

Exceptions

1. Designated landscapes can include younger stands, if these occupy less than 20% of the total area and the management commitment is adhered to.
2. If natural disturbance alters stand or landscape structure to a point below the designation threshold, the previous designation can be maintained if the management commitment is adhered to.

DESCRIPTION OF NORTHERN HARDWOOD COVER TYPE

Overstory Composition

Any combination of sugar maple, beech, basswood, white ash, and yellow birch comprises more than 50% of the basal area in stands of forest trees with average DBH greater than or equal to 5 inches, or more than 50% of the stems in sapling and seedling stands (WDNR 1990).

Sugar maple typically is the dominant species in northern hardwood stands in Wisconsin. In eastern Wisconsin, beech sometimes is dominant. Basswood is the most common associate of sugar maple, but only occasionally dominates. White ash and yellow birch are common minor associates, but rarely dominate stands.

Within the northern hardwood cover type, the predominant associates in Wisconsin currently are (1996 FIA): red maple, red oak, hemlock, white pine, and balsam fir. Many other tree species can be found as occasional associates.

Between northern and southern Wisconsin, there are some compositional differences within the northern hardwood forest cover type. Yellow birch, hemlock, and balsam fir are common associates in the north, but uncommon in the south. In contrast, oaks (especially white oaks) and hickories play relatively greater compositional roles in the south. In addition, there are consistent differences in the composition of herbaceous layer communities, north and south of the tension zone.

Site Characteristics – Soils and Habitat Types

The northern hardwood cover type develops and grows best on mesic sites with well drained to moderately well drained loamy soils; the very best soils are deep, well drained, silt loams. However, it occurs on a wide range of soil conditions, from well drained to somewhat poorly drained and from sands to clays. Dry, excessively drained sands and wet, poorly drained soils generally do not support the development of northern hardwood stands.

The northern hardwood cover type currently is much more common in northern than in southern Wisconsin. About 89% of sugar maple net growing stock volume occurs within the northern habitat type groups. For the other northern hardwoods, 96% of yellow birch volume, 77% of basswood volume, 69% of beech volume, and 58% of white/green ash volume occurs within the northern habitat type groups (Kotar *et al*. 1999).

The occurrence and growth potential of the northern hardwood cover type, and of the individual species comprising the type, vary by habitat type groups and habitat types. Current relative occurrence and relative growth potentials for the northern hardwood cover type by generalized habitat type groupings are:

- Mesic sites
    - Predominant cover type in northern Wisconsin
    - Common cover type in southern Wisconsin
    - Relative growth potentials range from good to excellent
- Mesic to wet-mesic sites
    - Common cover type in northern Wisconsin
    - Uncommon cover type in southern Wisconsin
    - Relative growth potentials range from poor (nutrient poor sites) to good (nutrient rich sites)
- Dry-mesic sites
    - Common cover type in northern Wisconsin
    - Uncommon cover type in southern Wisconsin
    - Relative growth potentials range from poor to fair
- On dry and wet sites, the northern hardwood type generally does not develop.

Detailed information can be found in Kotar and Burger 1996, Kotar *et al*. 1999, Kotar *et al*. 2002, and Wisconsin DNR 1990 (2004).

Succession and Stand Development

The principal late-successional (potential climax) species are sugar maple and beech. Important potential associates are hemlock, yellow birch, red maple, basswood, and ashes. Species whose predominance characterize mid-successional stands are yellow birch, red maple, basswood, ashes, white pine, and red oak; typically, sugar maple or beech are also significantly present. The most common early-successional species to occur on sites that succeed to northern hardwoods are aspen and white birch.

In Wisconsin, the northern hardwood forest cover type is a potential climax community type on most dry-mesic, mesic, and mesic to wet-mesic, nutrient medium to rich sites. The only major late successional competitor is hemlock (primarily north of the tension zone). The northern hardwood and hemlock-hardwood cover types are similar and often intermingled. At the extremes of this range of site types, fir-spruce, red maple, and ashes can become relatively more important in late-successional communities.

The northern hardwood forest type is an important late-successional community in Wisconsin, because the characteristic species are well adapted to prevailing climatic and site conditions, are well adapted to widespread disturbance regimes, are tolerant to moderately tolerant of shade, and are relatively long lived. Sugar maple and beech are classified as very tolerant; trees can respond to release following extreme and prolonged suppression. Basswood and white ash are tolerant, and yellow birch is intermediate in shade tolerance. Sugar maple, beech, and yellow birch can live for 300-400 years, and basswood for 200-250 years. As a potential climax community type, once established, the northern hardwood forest type generally will persist until a catastrophic disturbance (e.g. intense fire, repeated fires, human clearing) removes the over- and understories or climate change results in significant ecological change.

Northern hardwood communities can replace themselves compositionally following catastrophic disturbance when conditions are conducive. Blowdown, clearcutting, and heavy partial cutting can release advanced regeneration, as well as stimulate seeding and sprouting. These disturbances often result in the establishment of even-aged, mid- to late-successional northern hardwood communities in the stand initiation and stem exclusion stages of stand development. Most current northern hardwood stands in Wisconsin are in this condition; many of these originated following logging in the early to mid 1900's. Most current stands are essentially even-aged (40-90 years old), although older remnant trees (low value trees not harvested during early logging) are not uncommon. Sometimes, depending on conditions, catastrophic disturbance can result in stand conversion to an early-successional composition (*e.g.* aspen-white birch) or to temporary open land (*e.g.* grass, other herbs, or shrubs).

Eventually, the mortality or cutting of trees with large crowns results in demographic transition. This developmental stage is characterized by the transition from an even-aged condition, dominated by a single cohort, to an uneven-aged condition and the eventual elimination of the original cohort. Management through partial cutting of large crowned trees greatly accelerates the development of this transitional condition as compared to natural processes. Managed stands in the process of conversion from even-aged to uneven-aged conditions are becoming more common in Wisconsin. Few unmanaged second-growth stands in Wisconsin have fully reached this developmental stage.

Old multi-aged northern hardwood communities have many different ages and sizes of trees and an uneven canopy. Canopy replacement occurs through gap dynamics. Potentially, this stage can be achieved several hundred years (250-400) following a catastrophic disturbance, after the progressive elimination of the old even-aged dominants.

Although currently uncommon in Wisconsin, most regulated uneven-aged stands managed by the single-tree selection silvicultural system are mid- to late-successional and in a modified demographic transition developmental stage. Northern hardwood stands managed through uneven-aged silvicultural methods are submitted to regular, light to moderate severity disturbance. It is probably best to consider these stands maintained in a relatively permanent and modified state of demographic transition. True late-successional, multi-aged stands developed through natural processes are rare in Wisconsin (although common prior to Euro-American settlement).

Common Silvicultural Systems and Rotation Ages

Northern hardwood timber stands are managed utilizing even-aged and uneven-aged silvicultural systems (WDNR 1990). Generally accepted even-aged systems are shelterwood and overstory removal (one-step shelterwood). Recommended rotation ages range from 80-150 years. Even-aged management applies moderate and catastrophic intensity disturbances to maintain mid- to late-successional stands in the stand initiation to stem exclusion stages. Uneven-aged systems usually apply single-tree selection, but group selection methods are also utilized. Single-tree selection rotates trees based on stand structure and size classes. Most commonly, the recommended maximum size class is 24-plus inches DBH, but alternatives from 18-30 inches are also utilized. Uneven-aged management generally applies relatively frequent light to moderate severity disturbances to maintain mid- to late-successional stands in a modified demographic transition stage.

Disturbance – Natural and Human

Significant natural disturbances of northern hardwood ecosystems include weather events, fire, insects and diseases, and herbivory. Wind has been the most significant agent of natural disturbance in both historic and current northern hardwood forests. Wind events result in patchy and sporadic disturbance to northern hardwood stands and landscapes; canopy disruptions may range from minor to catastrophic (natural disturbance regimes are further detailed in the next section on ecological characteristics).

Northern hardwood landscapes tend to be moist and fire resistant. Both historically and currently, catastrophic fire in northern hardwoods has been infrequent to rare. Occasionally, small surface fires can occur or fire can follow windthrow. Drought and landscape position can predispose these normally fire resistant stands to fire. Fire is most likely to occur where northern hardwoods are located near fire prone conifer forests, oak forests, savannas, or grasslands. One catastrophic fire can temporarily convert a northern hardwood stand to another composition, whereas repeated fires can essentially eliminate northern hardwoods from a landscape.

In current times, herbivory by deer can significantly impact stand regeneration and future composition. The impacts of potential climate change are uncertain.

Human disturbance has become the dominant disturbance factor determining current forest composition, structure, and landscape pattern. Significant human disturbances of northern hardwood ecosystems include land use conversion, alteration of drainage patterns, fire management, forest management (especially logging), hunting, recreation, and introduction of invasive exotic species. Fire control policies and activities are facilitating the expansion of the northern hardwood type into areas historically dominated by other communities (*e.g.* savannas, oak forests, pine forests). Land use decisions are critical in determining the distribution of forests and their landscape context. Forest management decisions are critical in determining forest composition and structure.

Geographic distribution

Historic

At the time of Euro-American settlement (mid-1800's), the northern hardwood forest type primarily occurred in northern Wisconsin (Province 212) where it was common (Figures 11-1 and 11-2) (Finley 1976, Schulte *et al*. 2002, Bolliger *et al*. 2004). Studies of characteristic vegetation occupying Wisconsin landscapes at this time generally do not clearly separate the northern hardwood and hemlock-hardwood forest types. These two types together were predominant in most Sections (J, X, Q, T, Z) within Province 212, except for K and Y in the extreme northwest (Appendix A, Fig. A.2). Hemlock was the single species of greatest prominence throughout much of this area. On glacial sediments in northern Wisconsin, characteristic associations were comprised of mixtures of hemlock, yellow birch, sugar maple, and beech (in eastern Wisconsin), with basswood, elm, and white pine as important associates. The abundance of hemlock, yellow birch, and elms has declined significantly since Euro-American settlement. In contrast, in southern Wisconsin (Province 222) northern hardwoods were uncommon, due to the fire regime that dominated the landscape. However, natural firebreaks (e.g. rivers, extensive wetlands) sometimes protected and enabled the persistence of isolated northern hardwood landscapes surrounded by these fire dominated ecosystems.

At the time of Euro-American settlement, about 60-70% of all closed forests in Wisconsin were northern hardwood or hemlock-hardwood (Frelich 1995). Most of these forests were old and uneven-aged. Early developmental stages (i.e. stand initiation and stem exclusion) and early-successional species (*e.g*. aspen and white birch) typically comprised only 5-20% of the extensive northern hardwood landscapes (Lorimer and Frelich 1994, Frelich 1995, Frelich and Reich 2003).

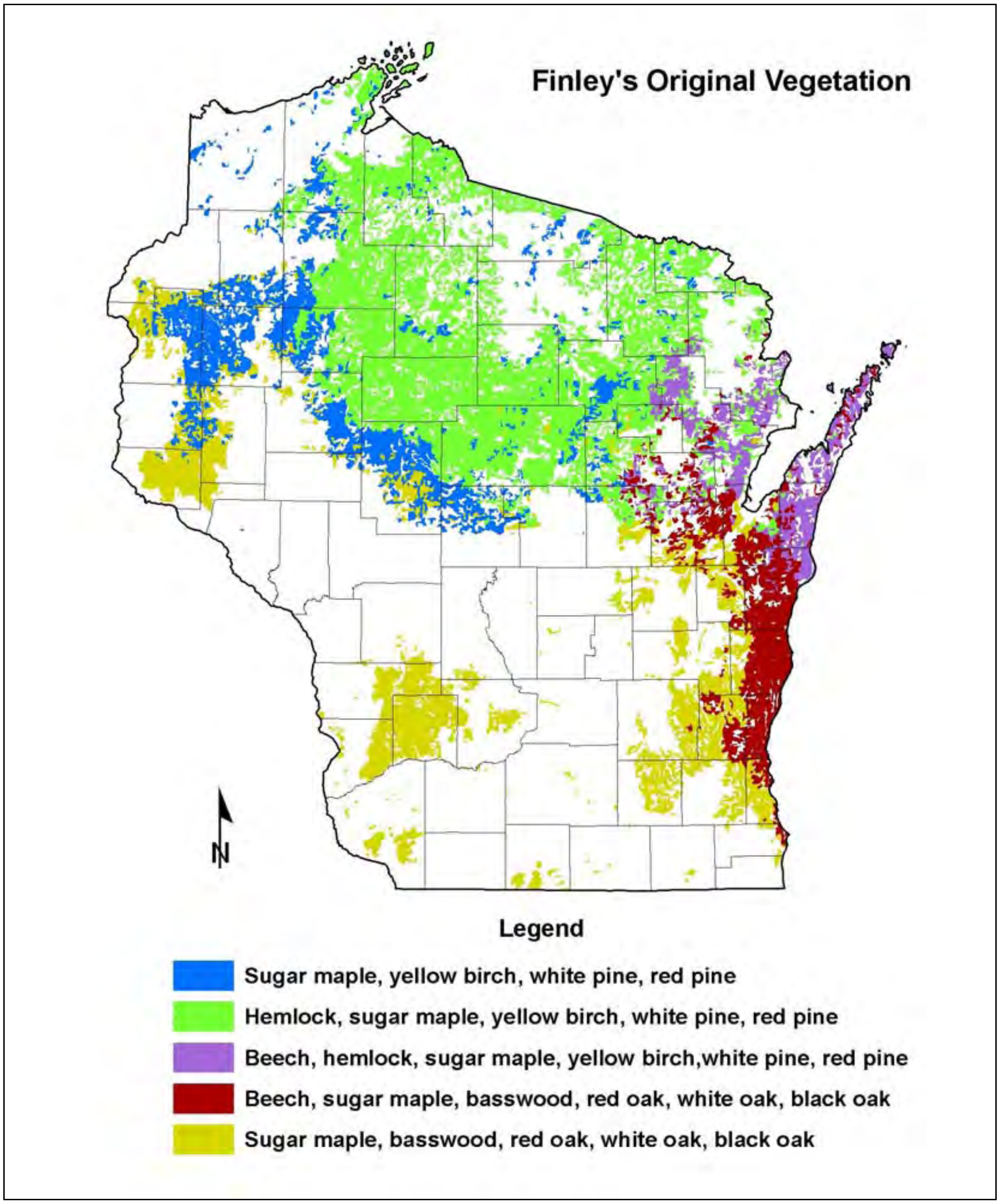


Figure 11-1. Historic statewide distribution of northern hardwood and hemlock-hardwood forest cover types from *Original Vegetation Cover of Wisconson* by R.W. Finley (1976).

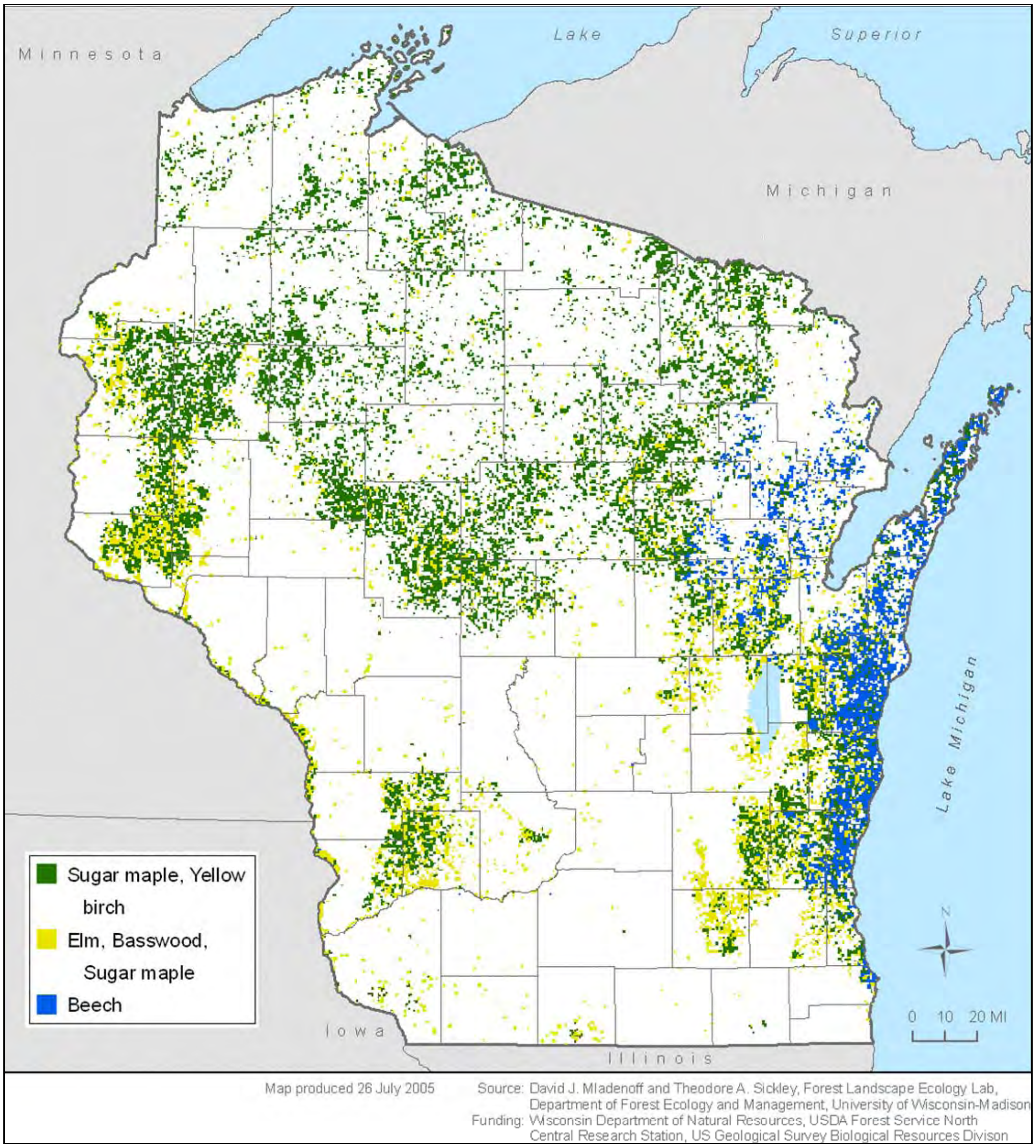


Figure 11-2. Historic statewide distribution of northern hardwood forest cover type from *Land Cover of Wisconsin Prior to Widespread Euro-American Settlement (1832-1866)* by D.J. Mladenoff and T.A. Sickley (2005 unpublished).

<u>Current</u>

The northern hardwood forest type is the most common cover type in Wisconsin, and is increasing its representation. In northern Wisconsin, it is the most common cover type along with aspen. In southern Wisconsin, it has become more common, and probably will continue to become more common, principally due to fire control and social attitudes concerning forest management and disturbance. In the south, it is a common cover type along with oak and central hardwoods.

Summary data from Wisconsin's fifth statewide forest inventory and analysis (FIA 1993-1996) elucidates the following trends (Schmidt 1998, Kotar *et al*. 1999):

a. The maple-basswood forest type occupied approximately 5.3 million acres of timberland (34% of timberland area) statewide, making it the most abundant type. The type gained about 1.3 million acres between 1983 (Spencer et al. 1988) and 1996; this was the largest real area gain for any forest type.
b. Northern Wisconsin (NE & NW survey units) was home to 66% of the maple-basswood statewide timberland area. Here, the type comprised 37% of the timberland area. This region contained 83% of the statewide sugar maple volume.
c. Maple-basswood timberland acreage was distributed among age classes as follows: 1-40 years contained 25% of acreage, 41-80 years had 59%, 81-120 years had 13%, and >120 years contained 2% of acreage. There were about 105,400 acres of maple-basswood timberland with a stand age class >120 years; 55% of this area was in the northeast survey unit, and 25% was in the northwest. However, acreage in this age class declined from the previous inventory.
d. Sugar maple volume was distributed among diameter classes as follows: 5-11 inches contained 47% of volume, 11-21 inches had 45%, and 21+ inches with 7% of volume.
e. The maple-basswood forest type occupied approximately 49,000 acres of reserved forest land (24% of reserved forest land area) statewide, making it the most common reserved forest type. Of the total forest land area occupied by maple-basswood in Wisconsin, about 1% is reserved; of this, less than 10% is at least 120 years old.

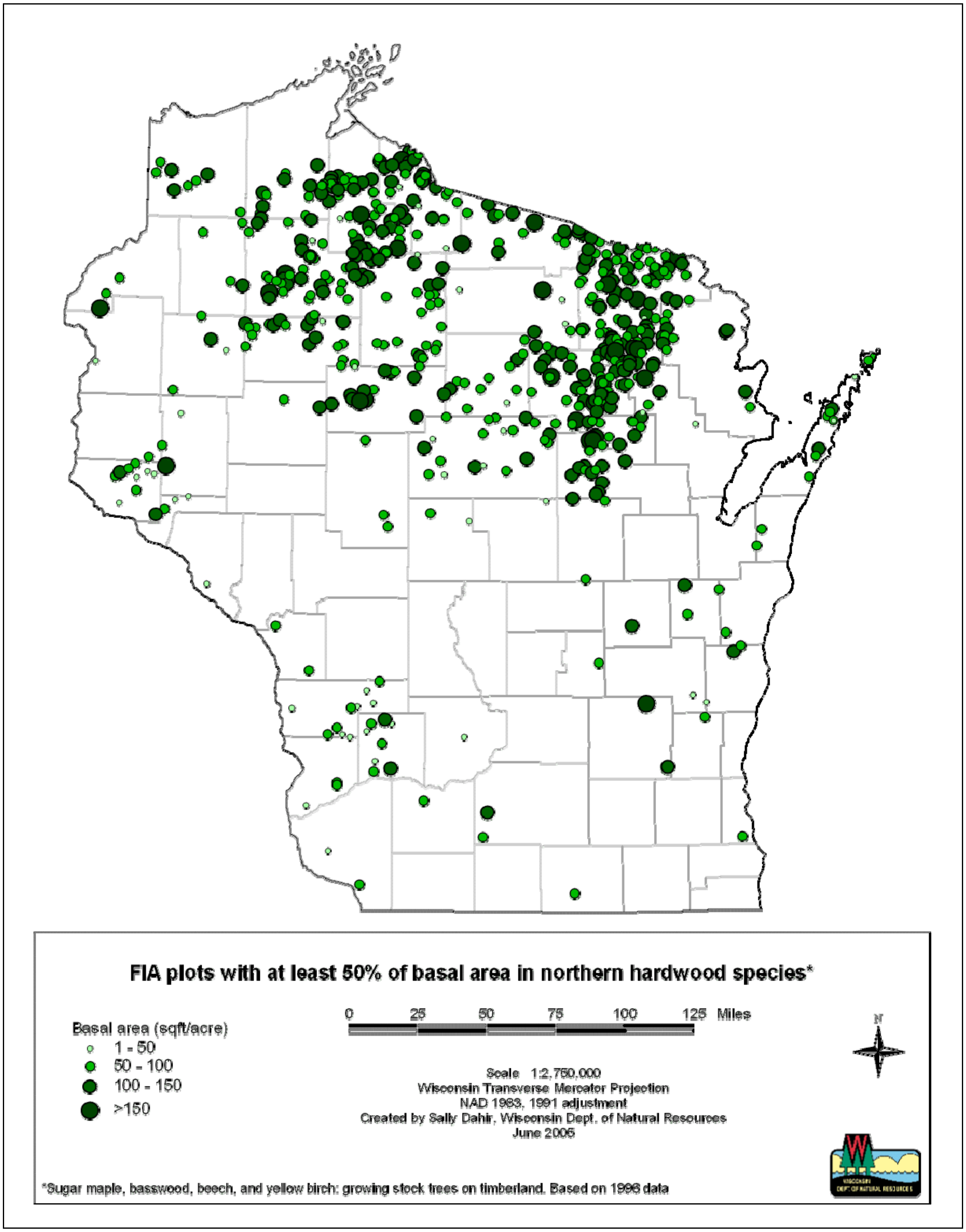


Figure 11-3. Current statewide distribution of northern hardwood forest cover type from 1996 Wisconsin Forest Inventory and Analysis (FIA). Map prepared by S. Dahir (2005 unpublished).

ECOLOGICAL CHARACTERISTICS OF RELICT AND OLD-GROWTH FORESTS

Old-growth forest conditions begin

Old, multi-aged, unmanaged northern hardwood communities have many age and size classes of trees, including numerous old trees, and an uneven canopy. There are few or no remnants left from the original cohort that initiated stand development following catastrophic disturbance. Canopy replacement occurs principally through gap dynamics. Most stands will exhibit non-equilibrium age structure reflecting episodic recruitment of new age classes into the canopy (Frelich and Lorimer 1991, Frelich 2002). Although uncommon, a shifting-mosaic steady state can be attained if developmental processes and light severity disturbance maintain consistent low rates of tree mortality (Borman and Likens 1979, Frelich 1995, Dahir and Lorimer 1996, Frelich and Reich 1996, Kotar 1997, Runkle 2000, Woods 2000, Frelich and Reich 2003). In a strict sense, under natural conditions, several hundred years (250-400) without significant exogenous disturbance are required to reach this state. However, within this period, the occurrence of a moderate disturbance event that significantly impacts the canopy and alters stand age structure can be expected. In old-growth northern hardwood forests, large diameter, standing and downed coarse woody debris is present.

In practice, old-growth conditions begin when overstory trees become relatively old, mortality of large overstory trees is becoming significant, large canopy gaps are present, large coarse woody debris is accumulating, and stands either are or are becoming uneven-aged. Typically, these stands will be in the transition stage of stand development. Specific age and structural thresholds are identified as designation criteria B1 and B2.

Natural disturbance regimes

Significant natural disturbances of northern hardwood ecosystems include weather events (wind, snow, ice, hail, flooding, drought), fire, insects and diseases, and herbivory. Prior to Euro-American settlement, wind and ice storms were the principal disturbance agents impacting forest composition and structure in extensive northern hardwood landscapes in the Lake States. Although northern hardwood forests are generally considered fire resistant, fires did occur, especially following windthrow and drought, and adjoining fire prone landscapes. The frequency and severity of natural disturbance events ranged from frequent light severity events, to infrequent and moderate severity, to rare catastrophic events. As disturbance severity increases (*i.e.* greater canopy removal), the frequency decreases exponentially (*i.e.* becomes much less frequent). The interaction of disturbance type, severity, and timing results in a variety of disturbance regimes and potential forest stand and landscape impacts. For example, potential impacts on future vegetation composition and structure are quite different when comparing a single moderate blowdown, a single catastrophic blowdown, and a moderate blowdown followed by drought and intense fire.

Following is a classification of natural disturbance regimes in northern hardwoods (after Frelich and Lorimer 1991 and Frelich 2002). Although disturbances occur over a continuum of conditions, this classification can aid understanding of northern hardwood stand and landscape dynamics. Severity and frequency refer to individual events or the cumulative impacts of several events occurring within a decade. Within each disturbance class (*e.g.* 30-50% canopy removal), the lightest severities (*e.g.* 31%) occur somewhat more frequently than the average return interval, and the heaviest severities (*e.g.* 49%) occur much less frequently than the average (*i.e.* return intervals increase exponentially with increasing disturbance severity).

(1) Background mortality, characterized by scattered treefall gaps, resulted in less than 10% canopy removal per decade. Primary agents of disturbance were senescence, disease, and weather events with small-scale impacts.
(2) Light severity disturbance resulted in 10-30% canopy removal and had an average return interval of 55 years. These disturbance events had the greatest cumulative impact on canopy turnover.
(3) Medium disturbance resulted in 30-50% canopy removal and had an average return interval of 325-410 years. These events significantly influenced forest composition and structure within northern hardwood landscapes. Within relict old-growth stands, approximately 28% of the trees were recruited following disturbance events that removed at least 30% of the canopy. These meso-scale events modified stand structure and resulted in stands with non-equilibrium age structures with many age classes.
(4) Heavy to catastrophic disturbance resulted in greater than 50% canopy removal and had an average return interval of more than 1000 years. However, these events were highly variable in frequency and pattern depending on landscape position, physical site factors, biological development, and climatic variability. Blowdowns may have averaged about 100-300 acres, but ranged in size from very small to thousands of acres (Canham and Loucks 1984, Lorimer and Frelich 1994, Frelich and Reich 1996, Lorimer 2001).

The light and medium severity disturbances had the greatest cumulative impact on forest composition (succession) and structure (development).

Light severity disturbances and background mortality created canopy gaps caused by single and multiple treefalls (Frelich and Lorimer 1991, Runkle 1991, Lorimer and Frelich 1994, Dahir and Lorimer 1996, Frelich and Reich 1996). Most gaps were less than 0.1 acres in size. Approximately 60% of canopy trees were recruited (ascended into the canopy) following disturbances that removed less than 20% of the canopy. However, many trees were also recruited during more severe events that removed 20-40% of the canopy creating more abundant and some larger canopy gaps (Frelich and Lorimer 1991, Lorimer and Frelich 1994, Dahir and Lorimer 1996, Frelich 2002).

Estimates of annual canopy gap formation rates range from 0.4-2.0%, but rates of 0.5-0.9% are most commonly cited (Frelich and Lorimer 1991, Runkle 1991, Lorimer and Frelich 1994, Dahir and Lorimer 1996). Estimates of average canopy turnover time typically range from 100-200 years. However, canopy gap formation can be capricious, with both active and quiescent periods. Actual gap formation rates and canopy turnover times can be highly variable within and between stands.

Prior to Euro-American settlement, most northern hardwood stands were old and uneven-aged (Figure 11.4). Although some all-aged quasi-steady state stands existed, most northern hardwood stands were complex multi-aged stands with non-equilibrium age structure (Frelich and Lorimer 1991, Lorimer and Frelich 1994, Frelich 2002). About 10 – 20% of the northern hardwood forests in Wisconsin and Michigan may have been first-generation stands that originated following catastrophic disturbance. Northern hardwood quasi-equilibrium landscapes were composed of a matrix of old multi-aged stands (mostly with non-equilibrium age structure) with a shifting mosaic of inclusions of younger multi-aged and even-aged stands in different stages of development (Bormann and Likens 1979, Frelich and Lorimer 1991, Lorimer and Frelich 1994, Frelich and Reich 1996, Frelich 2002, Frelich and Reich 2003).

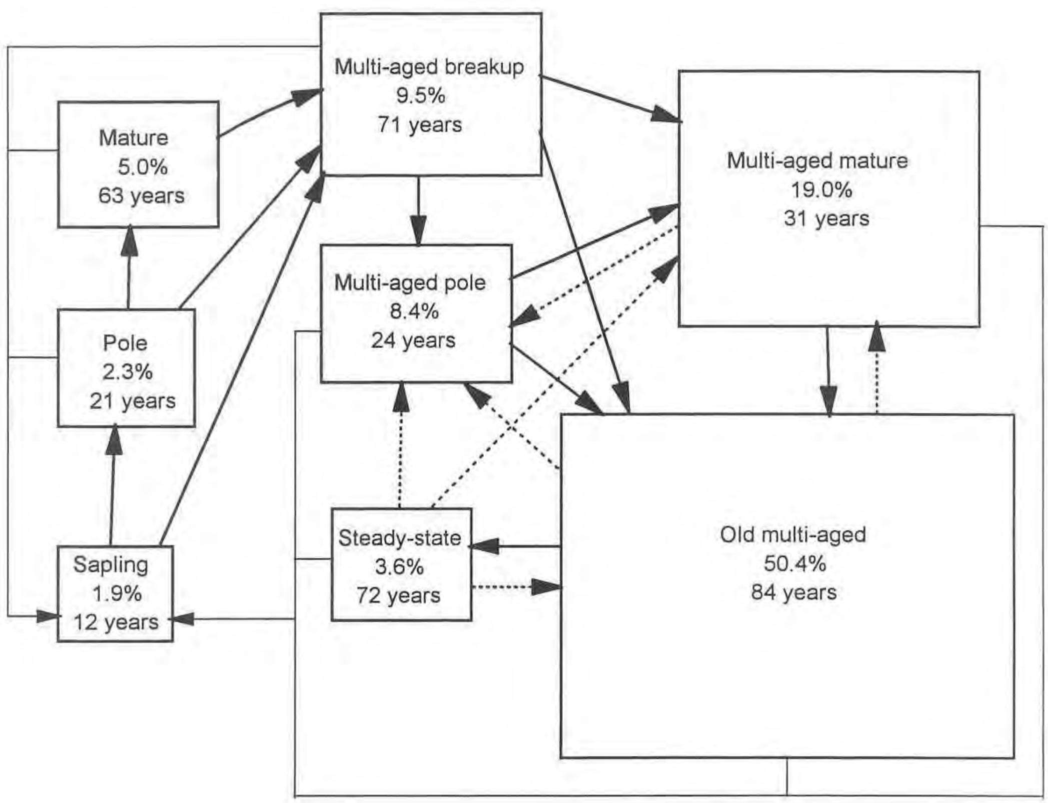


Figure 11.4. Box-and-arrow diagram of Upper Michigan, hemlock-hardwood forest landscape dynamics under the historic disturbance regime. The boxes represent eight stand types. The percentage of the landscape occupied by each stand type (also proportional to size of box) and average residence time for a stand in each type are shown in the boxes. The consolidated arrows with square corners represent transfers to the sapling stage after stand-leveling wind, solid single arrows represent advances in stand stature due to growth and development, and the dotted arrows represent reductions in stature caused by partial windthrow (from Frelich 2002).

Tree and Stand Age

Old-growth forests are older than typical managed forests. They are, or will be, uneven-aged. In old unmanaged northern hardwood stands, age distributions are highly irregular within and between stands. Typically, within a stand, canopy trees will range in age from 75-300 years. The average age often is between 115 and 175 years. Trees 250-300 years old often are common. The oldest trees in a stand can reach 300-400 years, but sometimes may be less than 200 years old (Bormann and Likens 1979, Stearns 1986, Frelich and Lorimer 1991, Runkle 1991, Lorimer and Frelich 1994, Frelich 1995, Singer & Lorimer 1997, Tyrrell *et al*. 1998, Lorimer *et al.* 2001, Crow *et al*. 2002).

In old unmanaged northern hardwood stands, mortality rates are high for saplings and large trees (Runkle 2000, Lorimer *et al.* 2001). A gap-maker is a relatively large-crowned canopy tree that dies. Following death, the open space previously occupied by the gap-maker is eventually occupied by another tree that competitively captures the vacated growing space. Gaps usually are captured by previously suppressed shade tolerant trees ranging in age from 20-150 years (Runkle 1991, Dahir and Lorimer 1996). Typical sugar maple gap trees average about 65 years old and 4 inches DBH at the time of release. An estimate of average time of release to time of death is about 143 years for sugar maple (Dahir and Lorimer 1996). Estimates of average canopy residence time typically range from 100-200 years (Frelich and Lorimer 1991, Runkle 1991, Dahir and Lorimer 1996, Woods 2000). The average age and size at time of death is 200-215 years and 17-20 (4-31) inches DBH for sugar maple; 195 years and 23 inches for yellow birch; and 300 years and 26 inches for hemlock (Dahir and Lorimer 1996, Lorimer *et al*. 2001). Many trees live beyond these average mortality values. For trees >26 inches DBH, annual mortality rates increase significantly and average 1.5-2.9% (Lorimer *et al*. 2001). Some gap-makers are probably approaching senescence, whereas others are succumbing to competitive stress. Many gap-makers die standing, breaking off at a variety of heights (becoming snags), some trees are uprooted, and many show evidence of substantial decay (Eyre and Longwood 1951, Dahir and Lorimer 1996, Runkle 2000, Lorimer *et al.* 2001).

Succession and Stand Structural Development

Compositional Change (succession)

As a potential climax community type defined by shade tolerant tree species, established northern hardwood stands are expected to progress through structural development and succession with relatively little change in overall species composition. Mortality of individual trees and small groups from senescence or minor disturbance will facilitate a shift to the most tolerant species (sugar maple, beech, and hemlock, perhaps with some basswood, ash, and red maple). However, moderate disturbance with gap/patch replacement can result in the increased representation of tolerant species (e.g. basswood, ash, and red maple), midtolerant species (*e.g.* yellow birch, oak, and white pine), and even some patches of intolerant species (*e.g.* aspen, white birch). Small spot fires and ground fires can also enable the maintenance of small patches of mid-tolerants and intolerants. Catastrophic disturbance can result in regeneration of the northern hardwood type (*e.g*. wind storm that results in the release of advanced regeneration) or conversion to an early- to mid-successional composition (*e.g*. fire that eliminates advanced regeneration and creates a mineral soil seedbed can facilitate aspen – white birch or white pine regeneration). Early- to mid-successional communities will eventually be replaced through relay floristics or gap replacement by another community, often northern hardwoods. Actual specific stand and landscape successional processes are complex. Major factors influencing composition following disturbance are: disturbance type, timing, and intensity; community composition; seed source availability; seed bank; seedbed condition; sprouting ability; and other site factors (Graham 1941, Stearns 1949, Braun 1950, Peterson and Pickett 1995, Frelich and Reich 1996, Kotar 1997, Tyrrell *et al.* 1998, Wood 2000, Lorimer 2001, Frelich 2002).

Tree and Stand Growth Rates

Tree growth rates are highly variable. In old-growth northern hardwood stands, some trees persist and grow very slowly in heavy shade beneath dense overstories, while other trees grow rapidly in the middle of large canopy gaps. Growth rates vary by site, stand condition, neighborhood characteristics, species, tree age, and tree size.

Old-growth stands tend to produce and maintain high levels of woody biomass. Bormann and Likens (1979) hypothesized that the greatest total accumulation of stand biomass is achieved near the end of the stem exclusion stage, and then declines slightly and fluctuates about a mean as stands become old and multi-aged. The concept of equilibrium in old-growth implies that net growth in stem volume and woody biomass is near zero (or fluctuates about a mean); growth and mortality are balanced.

Stand Structural Development

Old unmanaged forests are more structurally complex than managed forests (Runkle 1991, Crow *et al*. 2002). They have more large trees (>20 inches DBH), more basal area in dead trees (especially large ones), and sometimes more tree species. These forests are more heterogeneous, both within and between stands.

Old-growth northern hardwood stands generally will be in the later stages of stand development. They are the products of stand maturation and senescence. Representative developmental stages are demographic transition and multi-aged. In northern hardwoods, these two stages can be difficult to differentiate based on tree size and age distributions (Frelich 1995). These stages are characterized by the development of significant structural characteristics, including: uneven-aged, relatively old and large trees, broken canopy with large gaps, the accumulation of large diameter coarse woody debris, and high vertical and horizontal diversity.

During demographic transition, the onset of significant mortality among dominant large-crowned canopy trees creates relatively large canopy gaps (0.01-0.1 acres). Mortality is typically caused by processes related to tree senescence or by light severity exogenous disturbance. However, these stands are dominated by large old trees that are susceptible to disturbance of medium severity. New cohorts enter the canopy through gap dynamics, resulting in a transition from even-aged to uneven-aged structure. Depending on initial composition, a shift in species composition to more tolerant species can occur. In northern hardwood stands, this beginning of the development of old-growth conditions typically occurs around 150-200 years after stand initiation (Borman and Likens 1979, Kotar 1997, Lorimer *et al*. 2001, Frelich 2002, Frelich and Reich 2003).

Northern hardwood stands enter the multi-aged stage of stand development once the original post-disturbance even-aged cohort has been essentially eliminated. These uneven-aged stands are composed of irregular patches of trees of varying size and age. Canopy gap dynamics result in the regeneration and ascension of new age classes. Canopy gaps typically are caused by processes related to tree senescence and by irregular, light severity disturbance. Medium severity disturbances occur infrequently, but can have significant long-term effects on stand age structure. Within multi-aged northern hardwood stands, changes in species composition tend to occur slowly. The multi-aged condition will persist until a catastrophic disturbance levels the canopy and reinitiates stand development.

For northern hardwood forests, Frelich (2002) identified four subdivisions of the multi-aged stage: old, mature, pole, and steady state (Figure 11.4).

- The old multi-aged stage is characterized by the dominance of large, mature to old trees and a non-equilibrium age structure. These stands develop over 250 years or more free from catastrophic disturbance. The non-equilibrium age structure reflects variable disturbance severity and the episodic recruitment of new age classes into the canopy. This is the most common and most persistent developmental stage in unmanaged northern hardwood landscapes in the Lake States.
- Multi-aged mature and multi-aged pole stands can develop following moderately severe disturbances which reduce the stature (*i.e*. remove most of the larger and older trees) of multi-aged stands.
- Steady state stands are balanced all-aged stands (*i.e*. age structure characterized by reversed-J curve). They develop from old multi-aged stands that have experienced the regular formation of canopy gaps resulting only from endogenous development (e.g. senescence) and light severity exogenous disturbance. These stands are temporary and are eventually converted to non-equilibrium multi-aged structures by episodic disturbances or by medium severity disturbances. Northern hardwood stands in this stage of development were and are uncommon.

Both Frelich (2002) and Borman and Likens (1979) used the term “steady state” to describe a temporary structural condition of some northern hardwood stands. However, forest ecosystems are dynamic and do not achieve a long-term steady state in composition and structure (Borman and Likens 1979, Spurr and Barnes 1980, Mladenoff 2000, Runkle 2000, Woods 2000). Woods (2000) identified environmental change, natural disturbance variability, and competitive interactions as causes of continuous compositional and structural stand level changes. Even so, some forests may change relatively slowly and may temporarily exhibit equilibrium conditions (Borman and Likens 1979, Runkle 2000, Frelich 2002).

In a quasi or shifting mosaic steady state, conditions approximate a steady state and change is relatively slow. A shifting mosaic steady state northern hardwood stand is composed of a spatial mosaic of irregular patches (gaps) with vegetation of different ages (Borman and Likens 1979). Although individual gaps cycle through changes, the proportion of different gap ages within the stand remains relatively constant over time. Stands are all-aged with an equilibrium age structure. Species composition and abundance within the stand remain fairly constant over time. Borman and Likens (1979) theorized that total biomass fluctuates about a mean. Low intensity disturbance is characteristic, but moderate or catastrophic disturbance will negate the condition.

Within Wisconsin, the northern hardwood cover type offers perhaps the best potential to develop old-growth stands and landscapes that are dominated by large old trees, and that are relatively stable in composition and structure.

Tree Size Distribution

In old undisturbed northern hardwood stands, size class distribution typically is uneven and irregular. Within these stands, typical mean overstory diameters range around 20 inches, with trees greater than 18 inches diameter occupying about one-half of the canopy area, trees 10-18 inches diameter occupying another third, and the remainder occupied by gap saplings and poles (Lorimer and Frelich 1994). The maximum DBH typically is 30-40 inches, but can be as much as 50 inches (Tyrrell *et al.* 1998).

Stand Density

The following table summarizes the range of stand densities measured in many different old undisturbed northern hardwood stands in the north central and northeastern states (from Tyrrell *et al.* 1998, northern hardwood and beech-maple-basswood). Stand density is highly variable.

DBH size class (inches)	No. trees / acre	Basal area / acre (square feet)
≥ 4	60 – 300+	80 – 300
≥ 20	10 – 35 (0 – 85)	55 – 90 (0 – 130)
≥ 28	2 – 15 (0 – 43)	9 – 44 (0 – 50)

Canopy Stratification

Multilayered canopies that are highly irregular in terms of gap age and gap size are characteristic of old unmanaged stands. Variations in the size of trees and canopy gaps create a complex canopy structure (Crow *et al*. 2002).

Canopy Gap Size and Distribution

In old unmanaged stands, more than 80% of canopy gaps are created by the fall of single trees. Canopy gap area is determined by gap-maker crown size and is associated with gap-maker DBH. Most canopy gaps are less than 0.1 acres in size. Average gap size tends to range from 0.01– 0.09 acres, but most gaps are 0.01– 0.03 acres. Gaps in old, unmanaged stands are larger than in managed stands, because gap-maker trees tend to be larger (Runkle 1991, Lorimer and Frelich 1994, Dahir and Lorimer 1996).

Although infrequent, relatively large gaps (0.05-0.1, and up to 0.25 acres) often are represented (Runkle 1991).

Cavity Trees and Coarse Woody Debris

Cavity trees, large snags, and downed coarse woody debris generally are present, and will show maximal natural development in old unmanaged stands (Runkle 1991, Goodburn and Lorimer 1998, Hale *et al*. 1999, McGee *et al*. 1999, Fisk *et al*. 2001, Hura and Crow 2004). The development of large cavity trees and large coarse woody debris is directly related to increasing stand age, tree size, and management techniques (Goodburn and Lorimer 1998). Most typically, large trees die standing, become snags, eventually break and become downed logs, and decay (Eyre and Longwood 1951, Runkle 1991, Dahir and Lorimer 1996, Runkle 2000, Lorimer *et al*. 2001). Large diameter (greater than 16 inches) coarse woody debris is common in old, unmanaged northern hardwood forests, and uncommon in managed and second growth forests (Hura and Crow 2004). Hale *et al*. (1999) asserted that coarse woody debris was the most reliable indicator evaluated of old-growth condition.

In a study of northern hardwood old-growth by Goodburn and Lorimer (1998), there was an average of 4 cavity trees per acre greater than 18 inches DBH (double that in managed stands), including 1 cavity tree per acre greater than 24 inches DBH. These large cavity trees were most likely to be used for nests or dens.

Old, unmanaged northern hardwood forests usually have larger snags, more large snags, higher snag basal areas, and greater snag volumes than do managed stands, although the total number of snags typically is not significantly different (younger, managed stands tend to have many small snags) (Goodburn and Lorimer 1998, Hura and Crow 2004, McGee *et al.* 1999). Measured snag densities include: 6-32 stems per acre greater than 4 inches DBH (McGee *et al.* 1999), 2-8 stems per acre greater than 10 inches DBH (Runkle 1991), and an average of 7 stems per acre greater than 18 inches DBH (Goodburn and Lorimer 1998). Large snags greater then 24 inches DBH average 3-4 stems per acre, comprise about 20% of snag density, and are rare in managed stands (Goodburn and Lorimer 1998, Hura and Crow 2000)

In old unmanaged northern hardwood stands, snag basal areas range from 14-77 square feet per acre in stems greater than 4 inches DBH (McGee *et al*. 1999). Average snag basal areas measured include 25, 26, and 37 square feet per acre, which are 2-7 times the amounts measured in managed stands (Goodburn and Lorimer 1998, McGee *et al*. 1999, Hura and Crow 2000). Snags greater than 18 inches DBH comprised 85% of total snag basal area in one study (Hura and Crow 2000), and snags greater than 20 inches DBH comprised 70% of total snag basal area in another (McGee *et al.* 1999); these large snags rarely occur in managed stands. Runkle (1991) calculated an average annual snag formation rate of 0.3-0.8 snags greater than 10 inches DBH per acre per year.

The volume of downed coarse woody debris greater then 4 inches diameter in old, unmanaged northern hardwood forests averages about twice the amount found in younger, managed stands (Goodburn and Lorimer 1998, McGee *et al.* 1999). Particularly significant is the relatively high volume of large diameter (>16 inches) material (Goodburn and Lorimer 1998, McGee *et al.* 1999). Hura and Crow (2000) measured an average of 13 stems per acre greater than 8 inches diameter, and 4 stems per acre greater than 16 inches diameter.

<u>Pit and Mound Microtopography</u>

In old unmanaged northern hardwood forests, large trees commonly die standing and then break off at a variety of heights, becoming snags (Eyre and Longwood 1951, Dahir and Lorimer 1996, Runkle 2000, Lorimer *et al.* 2001). Less commonly, trees are uprooted.

Pit and mound microtopography is created when trees are uprooted (Schaetzl and Follmer 1990). Tree uprooting disturbs and mixes the soil, and is an important soil forming process (Schaetzl *et al.* 1989a, Schaetzl *et al.* 1989b). It exposes mounded mineral soil and creates relatively moist pits. Pit and mound sites are different in morphology, nutrient availability, and moisture content (Schaetzl *et al.* 1989b, Beatty 2003). Once created, tip-up mounds and pits remain intact (but diminishing) for long periods of time; large mounds are most persistent and can retain their integrity for hundreds of years (Schaetzl and Follmer 1990, Beatty 2003). Pit and mound microtopography can comprise more than 50% of the forest floor area within some stands (Beatty 2003).

The most common cause of uprooting is wind events, with catastrophic storms having the greatest impact (Schaetzl *et al.* 1989b). Principal factors that influence a tree's susceptibility to uprooting include: wind speed and direction; topographic exposure; soil factors such as depth, texture, and water content; root system; trunk strength; tree height; crown size and shape; and whether it is struck by a falling tree (Schaetzl *et al.* 1989a). Larger and older trees generally are more susceptible to uprooting than smaller and younger trees (Schaetzl *et al.* 1989a, Frelich and Lorimer 1991, Frelich and Reich 1996, Frelich 2002). Butt and root rots have been correlated to uprooting in older stands (Schaetzl *et al.* 1989a). Some landscapes are more susceptible to widespread uprooting due to climatic, topographic, or soil factors.

The composition and distribution of overstory vegetation can be influenced by pit and mound microtopography (Schaetzl and Follmer 1990). Exposed bare mineral soil on mounds provides a germination microsite that can favor the regeneration of some tree species (*e.g.* yellow birch). In some stands, the majority of trees regenerate and persist on mounds. Pits generally offer poor sites for the establishment of trees because of thick litter accumulations and wet conditions (Schaetzl *et al.* 1989b). However, pits can facilitate the persistence of some species (*e.g.* red maple) within stands.

Understory species spatial distributions are influenced by pit and mound microtopography. Some species are distributed across microsites, whereas others exhibit patchy distributions associated with specific microsites (Schaetzl *et al.* 1989b, Beatty 2003). Mounds generally support more species than do pits (Beatty 2003). Pits support fewer species, because thick leaf litter and wet conditions can interfere with successful germination and establishment (Schaetzl *et al.* 1989b, Beatty 2003). However, pits do facilitate the persistence of some species unable to compete on mounds or the undisturbed forest floor, but able to tolerate the limiting conditions characteristic of the pits (Beatty 2003). Spatial heterogeneity not only segregates some species, but also provides a range of microsite conditions that can be utilized by some species for local survival in response to environmental variation (Beatty 2003). Pit and mound microtopography creates spatial heterogeneity which enhances species richness of understory vegetation (Schaetzl *et al.* 1989b, Beatty 2003).

There have been few systematic studies that compare the abundance, distribution, and ecological function of tip-up mounds in old-growth and managed northern hardwood forests. Summarizing one study, Goodburn and Lorimer (1998) stated that "there were no statistically significant differences detected among treatments for percentage of stand area in recent pit and mound microtopography" (treatments were old and unmanaged, uneven-aged selection, and young and even-aged). In another study of old-growth hemlock stands (177-374 years old), Tyrrell and Crow (1993) found that tip-up mound area and density were not related to stand age. In both studies, all sites had been permanently forested.

Plowing or grazing can obliterate pits and mounds and reduce spatial heterogeneity (Beatty 2003). Second-growth northern hardwood forests growing on cutover sites not converted to agriculture often have pit and mound legacies (Beatty 2003). As these forests become older, the potential for further tree uprooting increases (Schaetzl *et al.* 1989a, Beatty 2003). In general, old-growth northern hardwood forests can be expected to be most susceptible to tree uprooting and most likely to develop relatively extensive pit and mound microtopography over the long-term.

Degree of Patchiness and Heterogeneity

Old, unmanaged northern hardwood forests tend to have a high degree of horizontal and vertical variability (Borman and Likens 1979, Frelich 2002, Franklin and Van Pelt 2004). Structural characteristics both within and between old unmanaged stands are highly irregular (Lorimer and Frelich 1994, Crow *et al.* 2002).

Understory (shrubs and herbs) Composition and Spatial Structure

In old, unmanaged northern hardwood forests, low intensity disturbance events causing single or multiple tree falls resulting in the formation of canopy gaps and pit and mound microtopography are important to the maintenance of spatial habitat heterogeneity (Beatty 2003). Variations in canopy structure and microtopography regulate available moisture, nutrients, light, and heat, which partially determine understory plant distribution. Spatial heterogeneity enables species segregation and facilitates species maintenance in response to environmental variation (Beatty 2003). Old-growth forests may provide habitat that could sustain larger populations of some rare species.

Differences in understory plant composition and structure among some developmental stages and management regimes in current northern hardwood forests appear to be relatively minor. In one study, Scheller and Mladenoff (2002) found that richness and cover were highest in managed uneven-aged stands, whereas the spatial patterning of plants was more patchy and heterogeneous in old relict forests. Likewise, Crow *et al*. (2002) showed that species richness was greater in managed uneven-aged forests than in old unmanaged forests, but that species distribution was more variable in old forests. Hale *et al*. (1999) found that there were no significant differences in plant species composition between old unmanaged forests and mature managed forests. These stand-level studies do not reflect impacts on species richness at the landscape level (*e.g.* the additional species sometimes found in managed stands are often common in the landscape).

Summarizing a study on the role of decaying logs as vascular plant habitat, McGee (2001) states "few herbaceous species exhibited distinct microsite preferences … and none were found to be obligately associated with decaying logs. This finding is consistent with previous studies of vascular herb communities on CWD." One fern (*Dryopteris intermedia*) and three species of tree seedlings (yellow birch, hemlock, and balsam fir) occurred at greater densities on log microsites, however required environmental conditions for recruitment of seedlings into larger size classes function independently of germination microsites.

Ecosystem Benefits

Old-growth northern hardwood forests support species and exhibit structural characteristics that are absent or less abundant in younger forests (Runkle 1991). They offer habitat diversity and often exhibit uncommon species compositions or populations. Old-growth northern hardwood forests offer great structural diversity (Stearns 1986) which provides variable habitat for many animal species. Important structural attributes that support a diversity of species include: multi-layered canopies, large old trees with large crowns and rough bark, large cavity trees, and large coarse woody debris (Dahir and Lorimer 1996, McGee *et al*. 1999, Hura and Crow 2004). These forests favor wildlife species that prefer late-successional, structurally diverse forests which offer unique habitat structure (Lorimer 2001). Some examples of species which prefer this unique habitat are: American marten, plethodontid salamanders, woodpeckers, and some Neotropical migrant birds, such as Black-throated Blue Warbler, Acadian Flycatcher, and Chimney Swift.

Some bird species, such as cavity-nesters, are most abundant in old unmanaged northern hardwood stands (Goodburn and Lorimer 1998). The inclusion of conifers can have positive effects on bird composition and abundance. High bird densities, high species richness, and distinctive assemblages have been associated with old hemlock forests. Additionally, certain species of ground-dwelling beetles have been shown to be preferentially associated with old-growth northern hardwood forests (Werner and Raffa 2000). These forests also can contain greater species richness of leaf litter spiders.

In old-growth northern hardwood forests, some kinds of fungi and lichens demonstrate greater species richness and greater abundance, generally dependent on the representation of large trees and large coarse woody debris (unpublished reports from UW-DNR northern hardwood old-growth study). Increased fungal and arboreal lichen diversity and abundance have been associated with increases in moth diversity and abundance, and consequently increased bird diversity (consumers of lichen and fungal feeding moth larvae) in boreal forests (Petterson et al. 1995, Schmiegelow and Monkkonen 2001); similar interrelationships could occur in northern hardwoods.

Clear benefits for vascular plant composition and abundance have not been demonstrated. Some studies indicate that some herbaceous species reach their optimum densities in old-growth hardwood forests (Duffy and Meier 1992, Matlack 1994, Goebel et al. 1999, McCarthy 2003). Other studies have found that species richness and abundance in managed uneven-aged northern hardwood stands are greater than or not significantly different from old unmanaged northern hardwood stands (Hale *et al*. 1999, McGee 2001, Crow *et al*. 2002, Scheller and Mladenoff 2002, McCarthy 2003, Roberts and Gilliam 2003). Roberts and Gilliam (2003) state, "the level of consistency in findings of these studies demonstrates the site-specific nature of herb layer responses to anthropogenic disturbances to forests … further research is needed to determine the influence of harvesting on herbaceous layer composition and diversity."

Old-growth northern hardwood forests can also provide functional ecosystem benefits. The relatively high level of coarse woody debris accumulates energy, carbon, and nutrients, and is a source of soil organic matter (Hura and Crow 2004). The additional diversity they display within stands and across landscapes may increase resiliency to changing environmental conditions (Stearns 1986). As reservoirs of biological diversity (genetic, species), they may provide an ecosystem seed for recovery following disturbance perturbations.

ECOLOGICAL CHARACTERISTICS OF OLD FORESTS

Old forest conditions begin when trees are older and larger than normally managed for. These thresholds are identified as designation criteria C1 and C2. Generally, these stands are, or are becoming, uneven-aged. Old forests may experience relatively frequent low to moderate intensity disturbances of either natural or human origin.

Northern hardwood old forest stands typically will be in the late stem exclusion or the transition (natural or modified) stages of stand development. This is a period of structural instability, changing from a mature even-aged to an old even-aged to a multi-aged condition. In natural systems, there is a relatively high potential for episodic disturbance. Forest management can utilize light to moderate intensity disturbance to direct compositional and structural change.

The development of ecological characteristics and benefits will depend on the management class assigned and the management strategy applied (see Management Considerations for Managed and Extended Rotation Management Classes). Old forests – reserved will develop into old-growth. Old forests – managed could develop into old-growth or be maintained as old forest, depending on management objectives and applied silviculture. Those perpetuated as managed forest should exhibit many characteristics and benefits associated with old-growth. The inclusion of human disturbance will result in somewhat more regulated and perhaps more homogeneous conditions, and a somewhat younger and perhaps less structurally complex forest. Old forests – extended rotation will be maintained in an old forest condition, with compositional and structural characteristics intermediate between old-growth and younger managed forests. Extended rotation forests can provide many characteristics and benefits associated with old-growth, but will be more regulated, more homogeneous, younger, and less structurally complex.

MANAGEMENT CONSIDERATIONS FOR RESERVED MANAGEMENT CLASS

Reserved forests are designated based on disturbance history, structural characteristics, and management goals and commitments. Reserved forest can contain any of the ecological classes: relict forest, old-growth forest, and old forest. Designated stands and landscapes are protected and relatively undisturbed by humans. Therefore, these exhibit, or potentially will exhibit, maximum old-growth characteristics. Typically, they will contain old and large trees for the species and site represented. They will have, or will develop, an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. These forests may represent the classic concept of the old growth climax northern hardwood forest.

Northern hardwood ecosystems are dominated by relatively shade tolerant species, but mid-tolerants may be common associates, and intolerant patches may occur. In reserved forest, successional and developmental processes modified by natural disturbance will determine compositional and structural change, although some indirect human influence and disturbance are unavoidable. In general, relatively stable late-successional associations are expected to develop, with increased representation of the most shade tolerant species. However, over hundreds of years, moderate disturbance events can be expected to impact many stands and provide the opportunity to maintain the representation of some mid-tolerant species in some stands and landscapes. Although uncommon in northern hardwood dominated landscapes, catastrophic disturbance can occur and can significantly alter stand composition and structure. These disturbances should be considered natural processes and part of the represented ecosystems.

Direct Human Disturbance

In relict forests, no significant (>10% canopy removal) direct human disturbance since Euro-American settlement (early 1800's) is permissible. Evaluation of historic human disturbance is based on clear evidence and best available information. If direct human disturbance is applied to a relict forest, then the forest will no longer meet definitional criteria and will no longer be classified as relict forest. When possible, relict forests will be designated as relict forest – reserved, irrespective of structural characteristics. The primary management goal of relict forest – reserved is the preservation of natural processes. Where relict forests are classified as uncertain management, potential future human impacts are unknown.

For old-growth – reserved and old forest - reserved, the primary management goal is the long-term development and maintenance of old-growth compositional, structural, and functional attributes within a minimally manipulated environment. Historic human disturbance is irrelevant if the other designation criteria are met. However, once designated, management activities are severely limited.

Allowable Management Activities in Reserved Forests (relict, old-growth, old forests)

Actual implementation of any of the following activities will depend on the planning and decision making process. Once designated as reserved forest, direct human disturbance is limited to:

a. Fire presuppression and suppression
    - Protection of lands adjoining the reserve.
    - Protection of the reserve – activities that protect the reserve from human caused fires and from externally ignited fires are acceptable. Fires that are ignited within the reserve through natural processes (*i.e.* lightning strikes) could be allowed to burn if there is no threat to human life or property.

b. Control of native insects and diseases
    Native insects and diseases are functional parts of natural processes. However, human modification of ecosystems can result in aberrant behavior. Unacceptable thresholds, relative to populations and impacts, could be defined.
    - Protection of lands adjoining the reserve.
    - Protection of the reserve – activities that attempt to protect the reserve from aberrant damage are acceptable.

c. Exotic organisms may be controlled and eliminated to the greatest extent feasible, while causing the minimum damage possible to the system being protected.

d. Herbivore populations may be limited to reduce negative ecological impacts. Populations and impacts should be monitored.

e. Research and monitoring activities may be facilitated. Monitoring can be utilized to document ecosystem responses to environmental change. Research should not significantly alter forest composition, structure, or function. Destructive sampling should be kept to a minimum.

f. Recreation management should be implemented . Impacts on forest composition, structure, and function should be controlled and limited. Limited foot trail systems are acceptable. Dispersed primitive camping could be acceptable in large reserves. Recreation could be encouraged for educational purposes. Hunting could be used to control animal populations. Motorized recreation should be limited.
g. Infrastructure within reserves should be kept to a minimum. In most cases, structures should be discouraged; when necessary, they should be primitive. In most cases, roads should be discouraged; when necessary, they should be narrow dirt or gravel tracks.

Specific prohibited management activities

a. Timber harvesting and salvage are not permitted.
b. Vegetation management to manipulate compositional, structural, or functional development or to simulate disturbance processes is not permitted (beyond acceptable practices previously identified).

Current Occurrence in the Lake States and Wisconsin

Relict Forest – Reserved

Frelich (1995, 2002) estimated that currently there are about 72,000 acres of relict northern hardwood and hemlock-hardwood forests in the Lake States. Most of this area is reserved. Three distinct landscapes contain most of these relict forests: the Porcupine Mountains (mostly state owned), the Sylvania Wilderness Area (federally owned), and the Huron Mountains (mostly privately owned), all in the upper peninsula of Michigan. The Porcupine Mountains and Sylvania Wilderness Area are considered large enough to be functional quasi-equilibrium landscapes. The estimated current northern hardwood and hemlock-hardwood relict forest area occupies less than one percent of the area it probably covered in the Lake States at the beginning of Euro-American settlement.

Frelich (1995) also estimated that there are less than 1000 acres of relict northern hardwood and hemlock-hardwood forests in Wisconsin.

Old-growth and Old Forests – Reserved

In Wisconsin, approximately 49,000 acres of the maple-basswood forest type are classified as reserved forest land (Schmidt 1998, Kotar *et al.* 1999); this represents less than 1% of the total statewide maple-basswood acreage. This forest type occupies about 24% of the statewide reserved forest land area, making it the most common reserved forest type. Not all land classified as reserved by FIA will meet the management requirements detailed above. Most reserved forest land is occupied by young second-growth forest; it is not relict, old-growth, nor old. However, some of these reserved maple-basswood forests offer potential opportunities for the development of northern hardwood old forests and eventually old-growth. It is estimated that currently less than 10% of the maple-basswood reserved forest land area is greater than 120 years old. Also, less than 5% of maple-basswood forestland with a stand age class greater than 120 years is reserved forest land (>95% is managed timberland).

MANAGEMENT CONSIDERATIONS FOR MANAGED AND EXTENDED ROTATION MANAGEMENT CLASSES

Old-growth and old forests can be designated as managed or extended rotation forests, based on structural characteristics and management goals and commitments. Historic human disturbance is irrelevant, if the other designation criteria are met. However, once designated, management activities are limited. To achieve management goals, these forests will have low intensity disturbances of human origin.

Traditionally managed northern hardwood forests lack some of the structural complexity characteristic of old, unmanaged forests (Runkle 1991, Crow *et al*. 2002). They have smaller canopy gaps, fewer large trees (>20 inches DBH), less basal area in dead trees, and sometimes fewer tree species. Also, they tend to be more spatially homogeneous. Crow *et al*. (2002) provide the following management suggestions to increase the structural complexity of traditionally managed forests:

- Increase the range of tree sizes
- Promote the development of multistoried canopies
- Increase the abundance and range of sizes for canopy gaps
- Retain and increase coarse woody debris
- Increase the recruitment of tree species other than sugar maple.

Although traditional silvicultural practices focused on timber production usually curtail the development of old-growth characteristics, innovative silvicultural treatments potentially could hasten the development of some desired old-growth attributes (Runkle 1991, Lorimer and Frelich 1994, Vora 1994, Frelich 1995, Tyrrell 1996, Singer and Lorimer 1997). Adaptive silvicultural practices that hasten the development of and maintain ecological attributes associated with old, unmanaged forests require innovation, variability, and conscientious application.

Relatively old managed and extended rotation forests will provide a range of social and ecological benefits. They offer the potential to manipulate ecological processes targeting the achievement of specific benefits. Ecological complexity is expected to be intermediate between young managed forests and old unmanaged forests. Compared to traditional management, the increased ecological diversity manifested in older forests may increase resiliency to changing environmental conditions (Stearns 1986). Many of the benefits associated with old unmanaged forests can be provided while still maintaining the ability to manipulate developmental processes and also provide additional social benefits. These adaptive management schemes offer the opportunity to provide a unique suite of ecological and social benefits.

Forest Management and Direct Human Disturbance – Considerations and Recommendations

Clear and detailed management goals and objectives are critical for the implementation of sustainable, science-based management of old-growth and old forests designated as managed and extended rotation. Goals and objectives will guide the development of silvicultural prescriptions and the application of vegetation management techniques. Management decisions and silvicultural practices will largely determine the development of ecological conditions. The ecological characteristics described for old, multi-aged, unmanaged forests should be promoted to the greatest extent possible consistent with the management goals and objectives. Site potentials and landscape factors should be included in the analysis of management options.

Managed and extended rotation forests will have, or will develop, an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. Uneven-aged silvicultural systems can be adapted and applied. The application of specific silvicultural treatments depends on management goals and objectives, stand condition, and site capability. Silvicultural treatments that could be adaptively applied include:

- Site preparation offers the opportunity to manipulate species composition, and to simulate the effects of natural disturbance.
- Release offers the opportunity to manipulate species composition and foliar height diversity, and to accelerate the growth of desired individuals.
- Thinning and improvement cutting offer the opportunity to manipulate species composition; size distribution; growth rates; foliar height diversity; size, number, and distribution of canopy gaps; and the development of coarse woody debris. Periodic thinning can maintain individual tree diameter and stand basal area growth rates at levels higher than normally expected in old unmanaged stands.

- Single-tree selection and group selection regeneration methods offer the opportunity to manipulate stand structure, composition, and regeneration.
  - In even-aged stands, adaptive conversion techniques should be applied to develop uneven-aged conditions.
  - Adaptively integrating variability in timing and intensity of single-tree selection, group selection, and thinning could partially simulate irregular low intensity disturbances that result in spatial heterogeneity.
- Sanitation practices enable the management of potential forest health problems.
- Salvage enables the realization of economic returns.

Single-tree selection tends to favor the regeneration of sugar maple and beech. Species diversity could be encouraged. The inclusion of conifers can improve ecological and social benefits. Techniques to encourage species diversity include:

- Selective cutting to favor desired species, to vary gap sizes, and to locate gaps near desired seed sources. Most gaps should be less than 0.1 acres in size.
- Thinning and improvement cutting to favor desired species
- Release to favor desired species
- Site preparation to prepare favorable seedbeds (could include development of nurse logs) and to remove competition (including sugar maple advanced regeneration).
- Planting (*e.g.* hemlock in small gaps and white pine and oak in larger gaps).

Desired structural characteristics of managed (old-growth and old forests) and extended rotation (old forest) forests include:

- Uneven-aged.
- Horizontal and vertical diversity. Diversity can be encouraged by the adaptation and heterogeneous application of uneven-aged techniques. Integrating active and passive management could also contribute to the development of diversity.
- Gaps – size, number, and distribution. Management could attempt to approximate gap sizes and distributions characteristic of old unmanaged forests. Most canopy gaps are less than 0.1 acres in size, and gaps .01-.03 acres tend to be most common. Average annual gap formation rates are commonly 0.5-0.9%. Distribution is highly variable. Heterogeneity in application is recommended.
- Large trees. The representation of large trees is directly related to increasing stand age and tree size, but representation can be influenced by management techniques. Management techniques will encourage the development and maintain the representation of large diameter (>18 and >26 inches) trees.
  - Retain at least 6 live trees/acre greater than or equal to 20 inches DBH, including 2 trees/acre greater than or equal to 28 inches DBH (McGee *et al*. 1999).
  - Increase single-tree selection diameter limits (McGee *et al*. 1999)
- Large diameter cavity trees, snags, and downed woody debris (Goodburn and Lorimer 1998, McGee *et al*. 1999, Hura and Crow 2004). These structural attributes are directly related to increasing stand age and tree size, but representation can be influenced by management techniques. In managed old forests and extended rotation forests, representation of these structural attributes generally is intermediate in abundance between old unmanaged forests and younger more traditionally managed stands. Management techniques will encourage the development and maintain the representation of large diameter (>18 inches) cavity trees, snags, and downed woody debris. Retain at least:
  - 4 snags/acre >12 inches DBH
  - 2 snags/acre >18 inches DBH
  - 1 snags/acre >24 inches DBH
  - 1 cavity tree/acre >18 inches DBH

Structural perturbations caused by natural disturbances should be integrated into the management regime.

Managed – Old-growth and Old Forest

The primary management goal is the long-term development and maintenance of some old-growth ecological attributes within environments where limited management practices and product extraction are allowed. Management will perpetuate old forest or old-growth age and structural characteristics. These uneven-aged forests will contain old and large trees for the species and site represented. Silvicultural manipulations are primarily intended to influence forest development to achieve specific management objectives. Timber harvests can be a tool to accomplish primary objectives. Traditional single-tree selection stocking guides generally would not be applied regularly to the management of these stands.

Typical reasons to manipulate forest development include:

- Accelerate development of old-growth structural attributes
- Influence species composition
- Simulate natural disturbance
- Forest protection
- Partial salvage
- Research
- Recreation management

Extended Rotation – Old Forest

The primary management goals include timber production and the development and maintenance of some ecological and social benefits associated with older forests. Adaptive management techniques that address the compositional and structural considerations outlined above will be applied. Management activities will perpetuate old forest age and structural characteristics. These uneven-aged forests will contain some old and large trees for the species and site represented. Most trees will be harvested before the onset of biological deterioration. These uneven-aged stands are maintained in perpetuity, but some trees are harvested while young, some at economic maturity, some are grown to approach biological maturity and then could be harvested, while some are reserved to live out their natural lifespans; therefore, the rotation is extended for a subset of the trees within an uneven-aged stand.

Extended rotation management of northern hardwood stands will apply adaptive uneven-aged management techniques to encourage compositional and structural diversity.

- Apply adaptive single-tree selection stocking guide based on 30-inch maximum size class.
- Encourage species diversity through selective marking and management of gap regeneration.
- Designate and maintain representation of at least four reserve trees per acre. Spatial distribution of reserve trees can be variable. Allow designated reserve trees to live out their natural life-spans. As they develop, they can provide large trees, cavity trees, snags, and downed woody debris.

In timber marking operations, utilize the 30-inch stocking guide. Trees should be evaluated and marked following traditional sustainable forestry procedures (i.e. stocking by size class and marking guidelines). Gaps are created, and should be recognized and managed, where individual large crowned trees or groups of poor quality trees are harvested. The four largest trees per acre should be considered reserve trees and will supply the recommended stocking in the largest size class (i.e. 24-30+ inches). Big tree silviculture concepts apply to northern hardwood stands managed on extended rotations.

The management of extended rotations will encourage some compositional and structural attributes characteristic of old, multi-aged unmanaged forests. However, age and size distribution will be regulated, and there will be fewer trees beyond traditional rotation age or size. The size and quantity of large trees, cavity trees, snags, and downed woody debris will be less developed. Regulated management will result in more regular gaps in terms of size, number, and distribution. Species composition will depend on management objectives, site capability, stand condition, and silvicultural treatments, however diversity should be encouraged.

Allowable Management Activities in Managed and Extended Rotation Forests (old-growth and old forests)

Actual implementation of any of the following activities will depend on the planning and decision making process. Once designated, direct human disturbance is limited to:

a. Salvage operations are permitted, but are subject to limits.
   - Managed – partial salvage is permitted. Up to 50% of salvageable materials, by species and size class, may be salvaged. In special cases, where significant negative impacts to forest health, forest fire protection, or forest aesthetics can be demonstrated, additional salvage harvesting could be approved.
   - Extended rotation – nearly full salvage is permitted. Some standing and downed coarse woody debris should be retained.

b. Timber harvest operations are permitted, but are subject to limits.
   - Managed – partial timber harvesting as a tool for vegetation manipulation is permitted. Some examples of potentially valid reasons to cut trees include: maintain vigor of selected trees; enhance composition, structure, or function; manipulate reproduction; simulate natural processes; or accomplish other management objectives (*e.g.* create a vista or firebreak). When merchantable trees are cut, up to 75% of the cut volume, by species and size class, may be harvested. Generally, economically low-value cut trees will be left as coarse woody debris. In special cases, where significant negative impacts to forest health, forest fire protection, or forest aesthetics can be demonstrated, additional harvesting could be approved.
   - Extended rotation – sustainable uneven-aged silvicultural systems to maintain vigorous growth, manipulate composition and structure, and produce high quality timber will be applied. As specified above, these silvicultural systems will be adapted to grow relatively larger and older trees, develop and maintain reserve trees, develop and maintain large standing and downed coarse woody debris, and encourage compositional and structural diversity.

c. Vegetation management to manipulate compositional, structural, and functional development; maintain the vigor of selected trees; and manipulate reproduction is permitted.
   - Managed – light thinning to manipulate composition (*e.g.* release yellow birch), accelerate structural development, and maintain vigor of selected trees; release reproduction; create gaps to stimulate reproduction; limited planting in gaps and underplanting to target the regeneration of specific tree species; and occasional site preparation in gaps to target the regeneration of specific tree species are permitted.
   - Extended rotation – silvicultural practices to accomplish management goals and objectives are standard.

d. Simulation of natural disturbance processes is permitted.
   - Managed – creating gaps of variable size and distribution to simulate low intensity natural disturbance is permitted.
   - Extended rotation – silvicultural practices to accomplish management goals and objectives are standard. Management practices that simulate low intensity natural disturbance are encouraged.

e. Fire presuppression and suppression – all necessary activities are acceptable.

f. Control of native insects and diseases – all necessary activities are acceptable.

g. Exotic organisms may be controlled and eliminated to the greatest extent feasible, while causing the minimum damage possible to the system being protected.

h. Herbivore populations may be limited to reduce negative ecological and silvicultural impacts.

i. Research activities may be facilitated to the extent desired.

j. Recreation management should be implemented. Impacts on forest composition, structure, and function should be controlled and limited. Acceptable recreational activities should be specified in the planning process and based on the achievement of management goals.

k. Infrastructure and roads should be planned and limited.

Current Occurrence in the Lake States and Wisconsin

In Wisconsin, maple-basswood forests older than 120 years represent less than 3% of total maple-basswood forest land acreage statewide (Schmidt 1998, Kotar *et al.* 1999). Most of this relatively old forest (>95%) is managed timberland.

Managed – Old-growth and Old Forests

The managed designation represents an innovative adaptive management paradigm. Currently, few forest stands in Wisconsin represent this combination of ecological and management requisites.

Extended Rotation – Old Forest

Although uncommon, some northern hardwood old forests are uneven-aged and being managed as extended rotation forest.

LANDSCAPE CONSIDERATIONS

Current Conditions and Landscape Concerns

Disturbance Regimes

Currently, anthropogenic disturbances are predominant in northern hardwood stands and landscapes. Disturbance is relatively frequent and highly variable in severity; light, moderate, and catastrophic disturbances are all common. The type, severity, and timing of disturbances, and resultant landscape patterns are drastically different than those processes which drove ecosystem dynamics prior to Euro-American settlement. Altered disturbance regimes have resulted in altered compositional, structural, and functional attributes within both plant and animal communities.

Grazing of understory plants by deer has become widespread and often intensive, and can alter species composition in stands and across landscapes. The increasing representation of exotic invasive species could alter forest composition and function. Climate change could induce significant changes in ecosystem processes.

Succession and Stand Development

Sugar maple, oak, and aspen currently are the predominant cover types in Wisconsin. Two species, sugar maple and red maple, are asserting increasing dominance at the expense of other associates. Currently, most northern hardwood forests in Wisconsin are young, even-aged, and in the stand initiation and stem exclusion stages of stand development. Older age classes and advanced developmental stages are poorly represented, and representation continues to decrease.

Landscape Composition and Structure

Altered disturbance regimes driven by anthropogenic activities (*e.g.* parcelization, utilization of forest ecosystems, and deforestation) have resulted in fragmented landscapes characterized by relatively small forest patches and abundant edges. Historical exploitation and homogeneous management regimes have resulted in decreased compositional and structural diversity. Structural characteristics of current northern hardwood stands and landscapes that are poorly represented include:

- Advanced developmental stages (i.e. transition and multi-aged)
- Large old trees with large crowns and rough bark
- Large cavity trees and coarse woody debris
- High vertical and horizontal diversity of structural and compositional attributes
- Large patches of relatively undisturbed older forests.

Structural diversity provides habitat diversity which helps maintain biological diversity. Examples of the compositional impacts of fragmentation, homogenization, and simplification include:

- Increased dominance of sugar maple and aspen
- Decreased representation of hemlock, yellow birch, white pine, and yew
- Increased dominance of deer
- Decreased representation of species that prefer either large patches of interior forests or structural attributes characteristic of old multi-aged forests (*e.g.* large coarse woody debris), such as some neotropical migratory birds, woodpeckers, American marten, plethodontid salamanders, some species of beetles and spiders, and some species of fungi and lichens. Species representation, populations, and community composition vary with stand and landscape composition and structure.

The maintenance of biological diversity potentially could be facilitated through adaptive forest management that recognizes compositional and structural deficiencies, and which implements techniques to increase representation.

Quasi-equilibrium Landscapes

Frelich (1995) stated, "Michigan's Porcupine Wilderness State Park and Sylvania Wilderness Area are the only presettlement-like upland forest landscapes in the Lake States." These contain extensive tracts of relatively undisturbed northern hardwood and hemlock-hardwood forests. Michigan's Huron Mountains also contain extensive tracts of relict northern hardwood forests, but the current extent is insufficient to meet quasi-equilibrium landscape criteria (Frelich and Lorimer 1991, Frelich 1995, Frelich 2002). Most other northern hardwood landscapes are fragmented and frequently disturbed by human activities. However, this forest type offers one of the best potentials for old-growth management in the Lake States.

Frelich (1995) proposes that quasi-equilibrium landscapes dominated by northern hardwood forests potentially could be developed on parcels that are at least 13,000 to 20,000 acres or larger. Prior to Euro-American settlement, relatively old and uneven-aged forests dominated northern hardwood landscapes on upland loamy soils. The typical landscape structure was:

- 84-91% uneven-aged northern hardwood,
- 7-12% even-aged northern hardwood,
- 1-4% even-aged aspen-birch, and
- 1-2% birch-maple

(Canham and Loucks 1984, Lorimer 2001, Frelich 2002, Frelich and Reich 2003).

Within these landscapes, windthrow was the predominant disturbance factor.

Conservation Design

The northern hardwood forest type is common in Wisconsin, is well adapted to prevailing climatic and site conditions, is well adapted to predominant disturbance regimes, can occur in all developmental stages, and is a late-successional community composed of shade tolerant and long-lived species. These characteristics offer the opportunity to develop and maintain significant diversity and representation in stand and landscape conditions. Management strategies that perpetuate northern hardwoods can range from passive, to low intensity and extensive, to intensive. A large variety of ecosystem attributes could be encouraged under different management systems.

Northern hardwood forests can be perpetuated in passively managed reserved forests (i.e. relict, old-growth, old forest) that target the development of old-growth conditions and the maintenance of biological diversity. Reserves can be small or large; ecological benefits are expected to increase with increasing reserve size. Infrequent moderate and catastrophic natural disturbance events that alter forest composition and structure should be expected. A robust system of reserves will consider potential disturbance regimes and facilitate the maintenance of ecosystem representation through replication. Buffers around reserves can be extensively managed as old-growth – managed, old forest – managed, and old forest – extended rotation to provide a variety of ecological and social benefits. Management of older forests also provides the opportunity to maintain corridors that connect similar stands and landscapes. The northern hardwood landscape matrix can be managed to produce social and ecological benefits by applying an array of adaptive management techniques ranging from extensive to intensive (e.g. uneven-aged, infrequently disturbed, and relatively old to even-aged with frequent disturbance and relatively short rotations).

Ecological Regions

A variety of statewide maps can help identify the ecological potential for the management of forested landscapes with significant representation of northern hardwoods. Some potentially useful maps are:

- *Sections and Subsections of Wisconsin* by Wisconsin DNR (2002), Appendix A, Figure A.2. This map depicts the National Hierarchical Framework of Ecological Units (NHFEU) in Wisconsin. Nested levels include two Divisions and Provinces, thirteen Sections, and forty-one Subsections (over two hundred fifty Land Type Associations are nested within the Subsections). Principal delineating criteria are climate, geology and geomorphology, hydrography, soils, vegetation, and historic disturbance regimes.
- *Ecological Landscapes of Wisconsin* by Wisconsin DNR (2001), Appendix A, Figure A.3. This map depicts sixteen ecoregions delineated by combining similar NHFEU Subsections.
- *Original Vegetation Cover of Wisconsin* by R.W. Finley (1976), Appendix A, Figure A.4. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is subjective and includes interpretation of survey notes.

- *Land Cover of Wisconsin Prior to Widespread Euro-American Settlement (1832-1866)* by D.J. Mladenoff and T.A. Sickley (2005 unpublished), Appendix A, Figure A.5. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is quantitative.

National Hierarchical Framework of Ecological Units (NHFEU)

The National Hierarchical Framework of Ecological Units can help analyze spatial distributions and temporal potentials for landscape management applications. Provinces, Sections, and Subsections are landscape units mapped at different geographic scales and characterized by unique associations of biophysical factors (*e.g.* climate, topography, landform, soil, vegetation) which differentiate land areas in terms of ecological capabilities and potentials for management (Appendix A, Fig. A.2).

Province 212 was historically dominated by northern hardwood and hemlock-hardwood old-growth forests. Sections 212 J, Q, T, X, and Z have significant areas with good biological potential for the development and management of northern hardwood forests. In addition, J, T, and X, have areas that are currently extensively forested. Sections 212 K and Y generally offer only poor to fair biological potential for the development and management of northern hardwood forests. Subsections can be similarly grouped based on characteristic northern hardwood potential and forest extent:

- good biological potential and extensive forests: Jb, Jc, Ta, Xc, Xd, Xe, Xf, Xg
- good biological potential but generally lacking extensive forests: Tb, Tf, all Subsections in Q and Z
- extensive forests, but limited biological potential: Ka, Kb, Tc, Te, Xa, Xb, Ya.

Throughout most of province 222, northern hardwood forests historically were poorly represented. However, most of Sections K, L, and M are characterized by sites (including climate) with the inherent capability to support the development of quality northern hardwood forests. The historic fire disturbance regime limited the development of northern hardwoods to only a few protected areas; the largest such area is centered on Subsection Ld. Currently, the dominant factors limiting the development of northern hardwoods are land use, seed sources, and, to some extent, time and forest management. Some exceptions, where biological potential generally is limiting, are Subsections Kb, Kc, and Lb. Section R offers poor biological potential for northern hardwood management.

Forest Habitat Type Classification System (FHTCS)

The forest habitat type classification system can be applied to temporal and spatial aspects of stand and landscape evaluation and management. In Wisconsin, northern hardwood forests can develop on mesic sites, and also on many dry-mesic, and wet-mesic sites that are nutrient medium to rich. The habitat type series associated with northern hardwoods are: sugar maple, sugar maple-hemlock, sugar maple – beech, sugar maple – hemlock – beech, sugar maple – basswood – white ash, and sugar maple – red maple. These series names indicate potential late-successional dominants on different site types.

Northern habitat type groups rated as having excellent to good potential for northern hardwood old-growth and old forest management are mesic, nutrient medium to rich and mesic to wet-mesic, nutrient rich. The habitat types are: AH, AOCa, ACaCi, AFAl, AFAd, AHVb, ATDH, ATD, AAs, ATFSt, ATFD, ATM, AFVb, and AHI, ACaI, ASaI, and ATAtOn.

Southern habitat type groups rated as having excellent to good potential for northern hardwood old-growth and old forest management are mesic and dry-mesic to mesic. The habitat types are: AFAs, AFAs-O, ATiH, ATiCa, ATiCa-Al, ATiCa-La, ATiFrCa, AFH, AFTD, ATTr, ATiSa, ATiSa-De, ATiDe-As, ATiDe-Ha, ATiDe, ATiFrVb, ATiFrCi, AFrDeO, and AFrDe. In addition, the southern mesic and dry-mesic to mesic *phases* offer good potential for growth and development if seed sources are available. The habitat types are: ATiAs(De), ATiFrCa(O), ATiDe(Pr), ATiCr(As), ATiCr(O), ATiFrVb(Cr), and AFrDe(Vb).

On wetter, dryer, or more nutrient poor sites, where the northern hardwood cover type can develop (e.g. dry-mesic and nutrient medium), northern hardwood old growth can potentially be managed, but tree size, growth rates, and rate of succession usually will be less.

REPRESENTATIVE STANDS AND LANDSCAPES FOR ECOLOGICAL CLASSES

Relict Forest

- Sylvania Recreation Area, Ottawa National Forest, MI, Reserved
- Porcupine Mountains State Park, MI DNR, Reserved
- Bose Lake Hemlock-Hardwoods State Natural Area, Chequamegon-Nicolet National Forest, Forest County, Reserved
- Catherine Lake Hardwoods, NHAL State Forest, Iron County, Reserved
- Flambeau River Hardwood Forest State Natural Area, Flambeau River State Forest, Sawyer County, Reserved
- Fox Maple Woods State Natural Area, Florence County, DNR, Reserved
- Jung Hemlock-Beech Forest State Natural Area, Shawano County, DNR, Reserved
- Waupun Park Maple Forest State Natural Area, Fond du Lac County, County, Reserved
- Abraham’s Woods State Natural Area, Green County, Univ. Wisc., Reserved
- Wyalusing Walnut Forest State Natural Area, Grant County, DNR, Reserved

Old-growth Forest

- Catherine Lake Hardwoods, NHAL State Forest, Iron County, Reserved
- Tenderfoot Reserve, Vilas County, TNC, Reserved
- Marinette County Beech Forest State Natural Area, Marinette County, County, Reserved
- Big Eau Pleine Forest State Natural Area, Marathon County, County, Reserved
- Schmidt Maple Woods State Natural Area, Clark County, Univ. Wisc., Reserved

Old Forest

- Lake Laura, NHAL State Forest, Vilas County, Reserved and Managed
- Wildcat Lake, NHAL State Forest, Vilas County, Extended Rotation or Managed
- Caroline Lake State Natural Area, Ashland County, DNR, Managed
- Rock Island Woods State Natural Area, Door County, DNR, Reserved
- Powers Bluff State Natural Area, Wood County, County, Reserved
- Eureka Maple Woods State Natural Area, Monroe County, DNR, Reserved

Literature Cited

Beatty, S.W. 2003. Habitat heterogeneity and maintenance of species in understory communities. *In*: Gilliam, F.S. and M.R. Roberts, eds. The herbaceous layer in forests of eastern North America. Oxford University Press, New York. pp 177-197

Bolliger, J., L.A. Schulte, S.N. Burrows, T.A. Sickley, and D.J. Mladenoff. 2004. Assessing ecological restoration potentials of Wisconsin (U.S.A.) using historical landscape reconstructions. Rest. Ecol. 12(1):124-142

Borman, F.H. and G.E. Likens. 1979. Pattern and process in a forested ecosystem. Springer – Verlag, New York

Borman, F.H. and G.E. Likens. 1979. Catastrophic disturbance and the steady state in northern hardwood forests. Amer. Scientist 67:660-667.

Braun, E.L. 1950. Deciduous forests of eastern North America. Free Press, New York. 596 pp.

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65(3):803-809

Crow, T.R., D.S. Buckley, E.A. Nauertz, and J.C. Zasada. 2002. Effects of management on the composition and structure of northern hardwood forests in Upper Michigan. For. Sci. 48(1):129-145

Dahir, S.E. and C.G. Lorimer. 1996. Variation in canopy gap formation among developmental stages of northern hardwood stands. Can. J. For. Res. 26:1875-1892

Duffy, D.C. and A.J. Meier. 1992. Do Appalachian herbaceous understories ever recover from clearcutting? Cons. Biol. 6:196-201

Eyre, F.H. and F.R. Longwood. 1951. Reducing mortality in old-growth northern hardwoods through partial cutting. U.S.D.A. For. Serv., Lake States For. Exp. Stn., Stn. Paper No. 24, St. Paul, MN. 13 pp.

Finley, R.W. 1976. Original vegetation cover of Wisconsin (map). USDA Forest Service, N. Cent. For. Exp. Stn., St. Paul, Minn.

Fisk, M.C., D.R. Zak, and T.R. Crow. 2002. Nitrogen storage and cycling in old- and second-growth northern hardwood forests. Ecology 83(1):73-87

Franklin, J.F. and R. Van Pelt. 2004. Spatial aspects of structural complexity in old-growth forests. J. For. 102(3):22-28

Frelich, L.E. 1995. Old forest in the Lake States today and before European settlement. Nat. Areas J. 15:157-167

Frelich, L.E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge, U.K.

Frelich, L.E. and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region. Ecol. Monogr. 61:145-164.

Frelich, L.E. and C.G. Lorimer. 1991. A simulation of landscape-level stand dynamics in the northern hardwood region. J. Ecol. 79:223-233

Frelich, L.E. and P.B. Reich. 1996. Old growth in the Great Lakes region. In: Eastern old-growth forests: prospects for rediscovery and recovery. Davis, M.B., ed. Island Press, Covelo, CA. 420 pp.

Frelich, L.E. and P.B. Reich. 2003. Perspectives on development of definitions and values related to old-growth forests. Environ. Rev. 11:S9-S22

Goebel, P.C., D.M. Hix, and A.M. Olivero. 1999. Seasonal ground-flora patterns and site factor relationships of second-growth and old-growth south-facing forest ecosystems, southeastern Ohio, USA. Natl. Areas J. 19:12-21

Goodburn, J.M. and C.G. Lorimer. 1998. Cavity trees and coarse woody debris in old-growth and managed northern hardwood forests in Wisconsin and Michigan. Can. J. For. Res. 28:427-438

Graham, S.A. 1941. Climax forests of the upper peninsula of Michigan. Ecology 22(4):355-362

Hale, C.M., J. Pastor, and K.A. Rusterholz. 1999. Comparison of structural and compositional characteristics in old-growth and mature, managed hardwood forests of Minnesota, U.S.A. Can. J. For. Res. 29:1479-1489

Hura, C.E. and T.R. Crow. 2004. Woody debris as a component of ecological diversity in thinned and unthinned northern hardwood forests. Nat. Areas J. 24:57-64

Kotar, J. 1997. Approaches to ecologically based forest management on private lands. Pub. NR-604. Univ. of Minnesota Extension Service.

Kotar, J. and T.L. Burger. 1996. A guide to forest communities and habitat types of central and southern Wisconsin. Dept. of For. Ecol. And Mgmt., Univ. of Wisconsin – Madison, Madison, Wisc.

Kotar, J., J.A. Kovach, and G. Brand. 1999. Analysis of the 1996 Wisconsin forest statistics by habitat type. USDA Forest Service, NC Res. Stn. Gen. Tech. Rep. NC-207. St. Paul, Minn. 166 pp.

Kotar, J., J.A. Kovach, and T.L. Burger. 2002. A guide to forest communities and habitat types of northern Wisconsin, second edition. Dept. of For. Ecol. And Mgmt., Univ. of Wisconsin – Madison, Madison, Wisc.

Lorimer, C.G. 2001. Historical and ecological roles of disturbance in eastern North American forests: 9,000 years of change. Wildl. Soc. Bull. 29(2):425-439

Lorimer, C.G. and L.E. Frelich. 1994. Natural disturbance regimes in old-growth northern hardwoods : Implications for restoration efforts. J. For. 92(1):33-38

Lorimer, C.G., S.E. Dahir, and E.V. Nordheim. 2001. Tree mortality rates and longevity in mature and old-growth hemlock-hardwood forests. J. Ecol. 89:960-971

Matlack, G. 1994. Plant species migration in a mixed-history forest landscape in Eastern North America. Ecology 75:1491-1502

McCarthy, B.C. 2003. The herbaceous layer of eastern old-growth deciduous forests. *In*: Gilliam, F.S. and M.R. Roberts, eds. The herbaceous layer in forests of eastern North America. Oxford University Press, New York. pp. 163-176

McGee, G.G. 2001. Stand-level effects on the role of decaying logs as vascular plant habitat in Adirondack northern hardwood forests. J. Torr. Bot. Soc. 128(4):370-380

McGee, G.G, D.J. Leopold, and R.D. Nyland. 1999. Structural Characteristics of Old-growth, Maturing, and Partially Cut Northern Hardwood Forests. Ecol. Appl. 9(4)

Peterson, C.J. and S.T.A. Pickett. 1995. Forest reorganization: a case study in an old-growth forest catastrophic blowdown. Ecology 76(3): 763-774

Petterson, R.B., J.P. Ball, K.E. Renhorn, P.A. Esseen, and K. Sjoberg. 1995. Invertebrate communities in boreal forest canopies as influenced by forestry and lichens with implications for passerine birds. Biol. Conserv. 74(1):57-63

Roberts, M.R. and F.S. Gilliam. 2003. Response of the herbaceous layer to disturbance in eastern forests. *In*: Gilliam, F.S. and M.R. Roberts, eds. The herbaceous layer in forests of eastern North America. Oxford University Press, New York. pp. 302-320

Runkle, J.R. 1991. Gap dynamics of old-growth eastern forests: management implications. Nat. Areas J. 11(1):19-25

Runkle, J.R. 2000. Canopy tree turnover in old-growth mesic forests of eastern North America. Ecology 81(2):554-567

Schaetzl, R.J., D.L. Johnson, S.F. Burns, and T.W. Small. 1989a. Tree uprooting: Review of terminology, process, and environmental implications. Can. J. For. Res. 19:1-11

Schaetzl, R.J., S.F. Burns, D.L. Johnson, and T.W. Small. 1989b. Tree uprooting: Review of impacts on forest ecology. Vegetatio 79:165-176

Schaetzl, R.J. and L.R. Follmer. 1990. Longevity of treethrow: Implications for mass wasting. Geomorphology 3:113-123

Scheller, R.M. and D.J. Mladenoff. 2002. Understory species patterns and diversity in old-growth and managed northern hardwood forests. Ecol. Appl. 12(5):1329-1343

Schmidt, T.L. 1998. Wisconsin forest statistics, 1996. USDA Forest Service, NC For. Exp. Stn., Resour. Bull. NC-183. St. Paul, Minn. 150 pp.

Schmiegelow, F.K.A. and M. Monkkonen. 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forest. Ecol. Appl. 12:375-389

Schulte, L.A., D.J. Mladenoff, and E.V. Nordheim. 2002. Quantitative classification of a historic northern Wisconsin (U.S.A.) landscape: mapping forests at regional scales. Can. J. For. Res. 32:1616-1638

Singer, M.T. and C.G. Lorimer. 1997. Crown release as a potential old-growth restoration approach in northern hardwoods. Can. J. For. Res. 27:1222-1232

Spencer, J.S., Jr., W.B. Smith, J.T. Hahn, and G.K. Raile. 1988. Wisconsin's fourth forest inventory, 1983. USDA Forest Service, NC For. Exp. Stn., Resour. Bull. NC-107. St. Paul, Minn. 158 pp.

Stearns, F. 1949. Ninety-years change in a northern hardwood forest in Wisconsin. Ecology 30(3):350-358.

Stearns, F. 1986. Ecological view of the second hardwood forest and implications for the future. In: Proceedings, the Northern Hardwood Resource: Management and Potential. Edited by G.D. Mroz and D.D. Reed. Mich. Tech. Univ., Houghton, Mich. pp. 51-66

Tyrrell, L.E. and T.R. Crow. 1993. Analysis of structural characteristics of old-growth hemlock-hardwood forests along a temporal gradient. *In*: Fralish, J.S.; McIntosh, R.P.; Loucks, O.L., eds. John T. Curtis, fifty years of Wisconsin plant ecology, Wisconsin Academy of Sciences, Arts & Letters, Madison. pp. 237-246

Tyrrell, L.E., G.J. Nowacki, T.R. Crow, D.S. Buckley, E.A. Nauertz, J.N. Niese, J.L. Rollinger, and J.C. Zasada. 1998. Information About Old Growth for Selected Forest Type Groups in the Eastern United States. USDA, Forest Service, Gen. Tech. Rep. NC-197. 507 pp.

Vora, R.S. 1994. Integrating old-growth forest into managed landscapes: a northern Great Lakes perspective. Nat. Areas J. 14(2):113-123

Werner, S.M. and K.F. Raffa. 2000. Effects of forest management practices on the diversity of ground-occurring beetles in mixed northern hardwood forests of the Great Lakes Region. For. Ecol. And Mgmt. 139:135-155

Wisconsin Department of Natural Resources. 1990 (2004). Silviculture Handbook. State of Wisconsin, Dept. Natl. Resour. Hndbk. 2431.5

Wisconsin Department of Natural Resources. 2001. Ecological landscapes of Wisconsin (map). State of Wisconsin, Dept. Natl. Resour., Madison

Wisconsin Department of Natural Resources. 2002. Landtype Associations of Wisconsin (map). State of Wisconsin, Dept. Natl. Resour., Madison

Woods, K.D. 2000. Dynamics in late-successional hemlock-hardwood forests over three decades. Ecology 81(1):110-126

Additional References – Northern Hardwoods

Anderson, H.W., B.D. Batchelor, C.M. Corbett, A.S. Corlett, D.T. Deugo, C.F. Husk, and W.R. Wison. 1990. A silvicultural guide for the tolerant hardwoods working group in Ontario. Ont. Min. Nat. Resour., Science and Technology Series, Vol. 7

Arbogast, C., Jr. 1957. Marking guides for northern hardwoods under the selection system. U.S. Forest Service Lake States For. Exp. Station Paper 56

Burns, R.M. and B.H. Honkala (Tech. Coords.). 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agric. Hndbk. 654. USDA Forest Service, Wash. D.C.

Crow, T.R., R.D. Jacobs, R.R. Oberg, and C.H. Tubbs. 1981. Stocking and structure for maximum growth in sugar maple selection stands. USDA Forest Service Res. Pap. NC-199

Erdmann, G.G. 1986. Developing quality in second-growth stands. In: Proceedings, the Northern Hardwood Resource: Management and Potential. Edited by G.D. Mroz and D.D. Reed. Mich. Tech. Univ., Houghton, Mich. pp. 206-222

Eyre F.H. and W.M. Zillgitt. 1953. Partial cuttings in northern hardwoods of the Lake States: Twenty-year experimental results. U.S. Forest Service Tech. Bull. 1076

Leak W.B., D.S. Solomon, and P.S. DeBald. 1987. Silvicultural guides for northern hardwood types in the Northeast. (Revised.) U.S. Forest Service Res. Pap. NE-603

Strong, T.F., G.G. Erdmann, and J.F. Niese. 1995. Forty years of alternative management practices in second-growth, pole-size northern hardwoods. I. Tree quality development. Can. J. For. Res. 25:1173-1179

Tubbs, C.H. 1977. Manager's handbook for northern hardwoods in the North Central States. USDA Forest Service Gen. Tech. Rep. NC-39

Tubbs, C.H. 1977. Age and structure of a northern hardwood selection forest, 1929-1976. Jorn. For. 75:22-24

CHAPTER 12

HEMLOCK

DESIGNATION OF ECOLOGICAL AND MANAGEMENT CLASS

Ecological Class

To meet minimum requirements for initial designation as relict forest, old-growth forest, or old forest, hemlock stands must meet one of the following criteria:

A. Relict Forest
Past and current stands on the site apparently have not been exploited, manipulated, or severely disturbed (>10% canopy removal) by humans since about 1800 AD, based on best available information.

  1. Relict Old-growth Forest: both relict and old-growth, meeting conditions detailed in both "A" and "B".

B. Old-growth Forest
At least 20% of stand basal area comprised of trees at least 210 years old.
Usually, uneven-aged or becoming so.
Indicators of old, multiaged stands:

- Uneven-aged, with trees in many different age and size classes
- Oldest trees >300 years
- Some trees >20 inches DBH, and often some trees >28 inches DBH
- Hemlock logs present in all decay classes, including very decayed, collapsed logs

C. Old Forest
At least 20% of stand basal area comprised of trees at least 150 years old.
Can be even-aged or uneven-aged.

Management Class

Once the ecological class is determined, the management goals and commitments will determine the designation of the appropriate management class: **reserved**, **managed**, **extended rotation**, or **uncertain management**. Each management class is defined by distinctive management goals, commitments, and limitations. Therefore, once designated, the different management regimes are expected to result in the development of distinctive forest conditions.

Exceptions

1. Designated landscapes can include younger stands, if these occupy less than 20% of the total area and the management commitment is adhered to.
2. If natural disturbance alters stand or landscape structure to a point below the designation threshold, the previous designation can be maintained if the management commitment is adhered to.

NOTE – See Chapter 11 – Northern Hardwood; the northern hardwood and hemlock cover types are similar and often intermingled (i.e. hemlock-hardwood).

DESCRIPTION OF HEMLOCK COVER TYPE

Overstory Composition

Hemlock comprises more than 50% of the basal area in stands of forest trees (average DBH greater than or equal to 5 inches), or more than 50% of the stems in sapling and seedling stands.

Within the hemlock cover type, the predominant associates in Wisconsin are: yellow birch, sugar maple, red maple, white pine, and balsam fir. In eastern Wisconsin, beech can be an important associate. On some moist sites, particularly within older stands, white cedar can be an important component. Many other tree species can be found as occasional associates.

Site Characteristics – Soils and Habitat Types

The hemlock cover type is most common and grows best on sites with well drained to somewhat poorly drained loamy soils. Preferred sites which retain moisture throughout the growing season often occur adjacent to streams, lakes, and wetlands, and along valley bottoms. Hemlock most frequently occurs on soils with medium nutrient availability, but also often occurs on nutrient rich soils. Competition with tolerant hardwoods may be less intense on nutrient medium, somewhat poorly drained soils.

Damp, nutrient poor sands (particularly loamy sands) occasionally support hemlock; sources of moisture may include high water tables, underlying deposits (e.g. sand outwash over loamy till), the presence of finer textured lenses or layers, or climatic effects (e.g. lake effect). Dry, excessively drained sands generally are not conducive to hemlock establishment and survival. Hemlock sometimes occurs on poorly drained muck and organic soils, usually as an associate in other forest types, such as white cedar.

Within Wisconsin, the hemlock forest type occurs almost entirely north of the tension zone; 99% of the statewide hemlock net growing stock volume on forest land occurs on northern habitat types. Most hemlock trees grow on northern mesic and wet-mesic sites. Within these two habitat type groups, hemlock currently occurs as only a minor species and cover type. Hemlock is a minor associate on wet sites. It is a rare associate on dry-mesic habitat types, and usually does not grow on dry sites. Detailed habitat type information can be found in Kotar and Burger 1996, Kotar *et al*. 1999, Kotar *et al*. 2002, and Wisconsin DNR 1990 (2004).

In southern Wisconsin, hemlock can be found near the Lake Michigan shoreline, and as rare outlier hemlock relics in the Driftless Region. Relics are restricted to sites that are comparatively cool, moist, and shaded, and often associated with Cambrian sandstone cliffs or gorges that receive groundwater seepage. These outlier hemlock communities contribute to the maintenance of regional diversity by supporting other plants and animals typically found further north.

Succession and Stand Development

Hemlock is a shade tolerant, long-lived tree that typically forms uneven-aged stands (Rogers 1978, Tubbs 1995, Goerlich and Nyland 2000). The slow development of suppressed saplings and small trees in forest understories is important to hemlock maintenance (Hough 1965, Rogers 1978, Kelty 1986, Lorimer 1995, Dahir and Lorimer 1996, Lorimer et al. 2001, Webster and Lorimer 2004). Hemlock can respond to release following extreme and prolonged suppression; suppressed 100-200 year old saplings can grow vigorously when released (Rogers 1978, Eckstein 1980, Lancaster 1985, Godman and Lancaster 1990, Foster and Zebryk 1993, Mladenoff and Stearns 1993, Anderson and Gordon 1994, Lorimer 1995, Tubbs 1995, Dahir and Lorimer 1996, Kelty 2000, Lorimer et al. 2001). Regeneration can establish with as little as 5% full sunlight, but early development is best at 20-25% full sunlight, and sapling growth is best at 25-45% full sunlight; large saplings and larger trees will grow most rapidly in full sunlight if adequate moisture is available (Goerlich and Nyland 2000). However, trees that have been suppressed for long periods typically respond to release with accelerated growth and can surpass trees that have developed under more sunlit conditions (Lancaster 1985). Hemlock is relatively long lived; trees often live 400 years, with a record age of 988 years (Rogers 1978, Godman and Lancaster 1990, Anderson and Gordon 1994, Tyrrell and Crow 1994a, Tubbs 1995). Hemlock trees often attain diameters of 35-40 inches and heights over 100 feet; recorded maximums are 84 inches DBH, and 175 feet tall (Rogers 1978, Godman and Lancaster 1990).

Prior to Euro-American settlement, hemlock forest was a widespread late-successional community type in northern Wisconsin. Hemlock was well adapted to prevailing prehistoric environmental conditions, including climate, site, and natural disturbance regimes. As a potential climax community type, once established, the hemlock forest type generally will persist until a catastrophic disturbance removes the overstory or environmental change (e.g. climate, disturbance regime, herbivory, insects, and disease) results in ecological conditions no longer conducive to hemlock regeneration and recruitment.

Disturbance regimes (type, severity, timing) influence stand composition and structural development. Hemlock forests are adapted to disturbance regimes characterized by frequent low severity disturbance, infrequent moderate severity disturbance (10-30% canopy removal), and rare severe disturbance. This wind driven disturbance regime enabled uneven-aged hemlock stands to perpetuate dominance for centuries to millennia (Frelich and Lorimer 1991, Frelich 2002).

Severe disturbance, such as windthrow, fire, and heavy cutting, typically reduces hemlock representation and often converts hemlock stands to a different composition (Willis and Coffman 1975, Eckstein 1980, Hix and Barnes 1984, Lancaster 1985, Foster 1988, Davis et al. 1994, Woods 2000a). However, if environmental and stand conditions are favorable (e.g. advanced regeneration, seed production, seedbed, sustained moisture), hemlock can regenerate in abundance following severe stand disturbance (Eckstein 1980, Hibbs 1982, Kelty 1986, Tyrrell and Crow 1994a, Lorimer 1995, Peterson and Pickett 1995, Orwig and Abram 1999, Loucks and Nighswander 2000, McLachlan et al. 2000, Woods 2000a). For example, if hemlock is present in the understory and not severely damaged by the disturbance of the overstory, it can respond to release; suppressed trees ten feet and taller can respond to release and compete with less tolerant regeneration to capture canopy space, whereas smaller advanced regeneration will probably become suppressed beneath the new overstory (Kelty 1986). Following severe disturbance of both overstory and understory vegetation, hemlock can sometimes regenerate in concert with a variety of other species; owing to slower early growth and high shade tolerance, hemlock can form a secondary canopy in even-aged stratified mixtures (Kelty 1986). In such cases, hemlock can increasingly dominate the stand as the less tolerant overstory dies-off. Most even-aged hemlock stands originated following fire or severe windthrow followed by fire (Miles and Smith 1960, Eckstein 1980, Tyrrell and Crow 1994a, Woods 2000a).

In northern Wisconsin, the hemlock forest cover type is a principal late-successional (potential climax) community type on many mesic and wet-mesic, nutrient medium to rich sites. The primary late-successional competitors are sugar maple and beech. The hemlock and northern hardwood cover types are similar and often intermingled. At the extremes of this range of site types, white pine, white spruce, balsam fir, white cedar, red maple, and ashes can become relatively more important in late-successional communities. Species whose predominance characterize mid-successional stands are yellow birch, red maple, basswood, ashes, white pine, white spruce, and balsam fir. The most common early-successional species to occur on sites that succeed to hemlock are aspen and white birch.

Hemlock and sugar maple are two associated late-successional dominants. Although intermingled, these two communities are able to occupy sites and exclude each other for long periods of time (Frelich et al. 1993, Davis et al. 1994, Davis et al. 1998, Woods 2000a). Dense hemlock stands influence energy and nutrient dynamics through impacts on microclimate, groundflora, humus type and thickness, and soil development (of chemical, physical, and biological properties) (Rogers 1978, Frelich et al. 1993, Davis et al. 1994, Mladenoff 1995). Hemlock stands develop environmental conditions that discourage sugar maple (Rogers 1978, Davis et al.1994, Davis et al. 1998). Similarly, sugar maple stands perpetuate conditions (e.g. litter) that discourage hemlock regeneration. "Positive neighborhood feedbacks on recruitment appear to reinforce the continued dominance of hemlock and sugar maple in their respective patches" (Frelich et al. 1993, Davis et al. 1998).

Hemlock Regeneration

In northern Wisconsin, tree regeneration in current hemlock stands tends to be either depauperate or dominated by hardwood species; abundant, well-distributed, well-established seedling/sapling layers dominated by hemlock are uncommon. Apparently, hemlock regeneration tends to be episodic, requiring coincidence in a number of factors infrequently achieved in the current environment in Wisconsin. Critical factors impeding hemlock regeneration on a regional scale are: climate, deer, disturbance regimes, historic land use, and ecosystem processes (Foster and Zebryk 1993, Mladenoff and Stearns 1993). Particularly in areas with moderate to high deer populations, hemlock regeneration in the 20th century appears to be insufficient to maintain long-term stand dominance (Frelich and Lorimer 1985, Dahir and Lorimer 1996, Rooney et al. 2000, Webster and Lorimer 2002).

Historic land use has altered large landscapes and changed ecosystem function. In some areas, hemlock seed sources were eliminated through logging, fire, and land use conversion (Rogers 1978). Hardwood forests have exerted dominance over large areas once dominated by hemlock; the thick hardwood leaf litter layer can be a barrier to hemlock regeneration. Modern forest management regimes are characterized by frequent disturbance events, moderate to severe canopy disturbance, and the creation of relatively large canopy gaps. Well-rotted, large downed woody debris is lacking. Modern disturbance regimes favor competitors such as sugar and red maple, or other higher timber value, faster growing, less moisture sensitive species. Conditions created rarely foster hemlock regeneration. When hemlock is able to initiate establishment, large deer herds often browse and kill seedlings.

The successful regeneration of hemlock requires specific favorable environmental conditions resulting from the coincidence of several environmental variables (Goder 1961, Willis and Coffman 1975, Rogers 1978, Eckstein 1980, Hix and Barnes 1984, Frelich and Lorimer 1985, Lancaster 1985, Godman and Lancaster 1990, Mladenoff and Stearns 1993, Anderson and Gordon 1994, Lorimer 1995, Tubbs 1995, Dahir and Lorimer 1996, Duchesne et al. 1999, Goerlich and Nyland. 2000, Rooney et al. 2000). Important factors that must be integrated include: well-distributed seed source; good seed crop and germination year; an appropriate seedbed, with sustained available moisture and limited competition; light canopy disturbance, that maintains partial shade, but allows bright light and warmth to enter; adequate available moisture during several consecutive growing seasons, influenced by climate, site, and stand characteristics; and freedom from browsing by deer. Successful hemlock regeneration, from germination to successful establishment of saplings, tends to be episodic in Wisconsin, following disturbance, and requiring appropriate surface conditions and several years of appropriate climatic conditions (Stearns 1951, Willis and Coffman 1975, Tyrrell and Crow 1994a, Lorimer 1995, Mladenoff 1995).

Moisture is critical to germination, seedling establishment, and the growth and survival of hemlock seedlings and saplings. Seedlings grow very slowly, with limited root development, during their first two years, and are susceptible to dessication. Seedling establishment requires several years of sustained moisture throughout the growing season (Graham 1941b, Stearns 1951, Rodgers 1978, Lancaster 1985, Godman and Lancaster 1990, Davis et al. 1994, Lanasa et al.1995, Lorimer 1995, Mladenoff 1995, Peterson and Pickett 1995, Strong 1995, Tubbs 1995, Tyrrell et al. 1998, Goerlich and Nyland. 2000). Within the Lake States, precipitation can be a limiting factor; drought can cause widespread seedling mortality (Mladenoff 1995, Tubbs 1995, Goerlich and Nyland. 2000). On some sites, the successful establishment of hemlock regeneration may require several years of above average rainfall.

Available moisture also is influenced by surface (litter and soil) conditions (Darlington 1930, Stearns 1951, Goder 1961, Rodgers 1978, Eckstein 1980, Lancaster 1985, Godman and Lancaster 1990, Mladenoff and Stearns 1993, Anderson and Gordon 1994, Davis et al. 94, Lorimer 1995, Tubbs 1995, Goerlich and Nyland 2000). Small, young seedling attempting to grow on thick, coarse litter, particularly hardwood leaf litter, often dessicate and perish; the litter often becomes too dry and it is difficult for young hemlock roots to penetrate thick leaf litter and reach the moist soil below. Disturbances that reduce the thick duff layer can facilitate the development of adequate seedbeds and the establishment of regeneration (Goder 1961, Rogers 1978, Eckstein 1980, Lancaster 1985, Godman and Lancaster 1990, Frelich et al. 1993, Mladenoff and Stearns 1993, Lorimer 1995, Tubbs 1995, Davis et al. 1998, Duchesne et al. 1999, Kelty 2000). Bare mineral soil (e.g. exposed by wind-thrown tip-ups) provides a good seedbed for germination, but must also retain moisture to facilitate establishment. The surface conditions created by light ground fires can provide an adequate seedbed for hemlock regeneration; however, fire probably was not a common regeneration mechanism in hemlock forests (Graham 1941b, Rogers 1978, Eckstein 1980, Godman and Lancaster 1990, Lorimer 1995, Tubbs 1995, Kelty 2000). Other surfaces that can retain the required moisture are well rotted logs and stumps. Good seedbeds for germination and seedling establishment include: mineral soil, mixed mineral soil and humus, thin well-decomposed litter, well-decomposed coarse woody debris, and moss mats (Goerlich and Nyland 2000).

Shaded, moist understory conditions protect hemlock seedlings from dessication. Shade also can reduce understory competition and facilitate the development of slow growing hemlock seedlings. However, undisturbed hemlock canopies can be very dense, allowing little light penetration, and often preclude the successful regeneration and establishment of even this very tolerant species. Regeneration generally requires light canopy disturbance; 70-90% residual crown closure permits increased light infiltration and warming of the soil surface without excessive surface dessication (Darlington 1930, Eckstein 1980, Lancaster 1985, Godman and Lancaster 1990, Anderson and Gordon 1994, Lorimer 1995, Tubbs 1995, Duchesne et al. 1999, Kenefic and Seymour 2000, Goerlich and Nyland 2000). In contrast, moderate to catastrophic severity disturbances that reduce canopy closure below 70% can increase surface dessication and plant competition, thereby precluding hemlock regeneration, and favoring competitors, such as sugar maple (Hix and Barnes 1984, Lancaster 1985). Hardwood leaf fall can smother small hemlock seedlings.

In uneven-aged forests, canopy gaps enable the regeneration of hemlock and its major associates. If sufficient light is available, most competitors grow faster in height than hemlock. Small canopy gaps, less than about 40 feet in diameter, can enable the establishment of hemlock along with a number of common competitors. However, subsequent gap closure through crown expansion of overstory trees and consequent shading suppresses established hemlock and results in the mortality of less tolerant tree species. Hemlock is able to persist and grow slowly in this suppressed condition while competitors perish. Thus, small gaps facilitate capture by hemlock by enabling establishment followed by one or more periods of suppression. Hemlock regeneration appears to be most successful in gaps smaller than 1000 square feet (36 feet in diameter), and particularly in gaps smaller than 450 square feet (24 feet in diameter). The main opportunity for hemlock to capture larger gaps is through the release of suppressed saplings or larger trees (Darlington 1930, Stearns 1951, Rogers 1978, Hibbs 1982, Foster 1988, Foster and Zebryk 1993, Lorimer 1995, Dahir and Lorimer 1996, Kenefic and Seymour 2000, Webster and Lorimer 2004, Webster and Lorimer 2005).

Deer browse hemlock, cause seedling mortality, and can limit hemlock regeneration success in areas with high deer populations (Swift 1948, Stearns 1951, Hough 1965, Willis and Coffman 1975, Rogers 1978, Anderson and Loucks 1979, Eckstein 1980, Whitney 1984, Frelich and Lorimer 1985, Godman and Lancaster 1990, Mladenoff and Stearns 1993, Davis et al. 1994, Frelich 1995, Lanasa et al.1995, Lorimer 1995, Mladenoff 1995, Peterson and Pickett 1995, Strong 1995, Alverson and Waller 1997, Tyrrell et al. 1998, Orwig and Abrams 1999, Goerlich and Nyland 2000, Loucks and Nighswander 2000, Rooney et al. 2000, Vasiliauskas and Aarssen 2000). In addition, deer can have significant impacts on the composition and structure of understory flora in hemlock stands and can cause local extirpation of some plant species (Rooney and Dress 1997). In regions with deep snow, stands of hemlock are often used as deer yards, and are heavily browsed over winter. Hemlock seedlings do not resprout, and when heavily browsed have little potential for regrowth and survival. Many competitors, such as sugar maple, can resprout, and have a greater potential to survive browsing. Hemlock is a slow growing species that persists in the shade of the forest and can remain within reach of deer for many years; even under ideal growing conditions, 6-10 years or more are usually required to attain heights less susceptible to deer browsing. Deer populations greater than 12-15 deer per square mile can severely impede hemlock regeneration (Loucks and Nighswander 2000).

Successful hemlock regeneration

The successful regeneration of hemlock; establishment of adequate numbers of seedlings and recruitment into the sapling layer; requires the sustained coincidence of a suite of ecological factors (Goerlich and Nyland 2000):

- Overstory density and spacing, that provides partial shade, but also allows some bright and warming light to reach the understory.
- Well-distributed seed sources, good seed crop, and good germination year.
- Adequate seedbed with available moisture and limited competition.
  Site preparation can improve seedbeds and control competition.
- Several consecutive years with favorable soil moisture conditions.
  Precipitation is an important input. Shade can facilitate the retention of surface moisture.
  Sites that retain moisture throughout the growing season increase opportunities for success.
- Freedom from browsing for several years.

Regeneration may pass through several episodes of suppression and release. Abundant, well-distributed seedlings at least three feet tall can provide an initial measure of success. A better measure is the presence of abundant, well distributed saplings at least 7-10 feet tall. Large saplings will respond well to overstory release. Management that successfully establishes hemlock seedlings and develops adequate representation of saplings will require at least 6-10 years or more.

Common Silvicultural Systems and Rotation Ages

Appropriate management systems and techniques for hemlock stands are uncertain (Eckstein 1980, Kelty 2000). Regeneration and recruitment (to sapling layer) can be difficult to obtain. Silvicultural methods have achieved highly variable levels of success. Regeneration appears to be most successfully managed on mesic to wet-mesic, nutrient medium sites; rich sites tend to be quickly dominated by sugar maple (Kotar 1995, Webster and Lorimer 2004). Currently, other than light thinning and experimental regeneration treatments, hemlock stands often are not actively managed (Eckstein 1995); reasons for lack of active management include: uncertain silviculture, low timber values, high ecological values, and aesthetic values. Sometimes, hemlock stands and patches are harvested and converted to other compositions.

When attempting to regenerate stands of hemlock, the shelterwood system, either two-cut or three-cut, with site preparation, is most typically recommended (Eckstein 1980, Lancaster 1985, Godman and Lancaster 1990, WDNR 1990, Anderson and Gordon 1994, Lanasa et al. 1995, Lorimer 1995, Pubanz 1995, Strong 1995, Goerlich and Nyland 2000). Success in applying the shelterwood system has been variable; the primary barrier has been competition from hardwoods. Recommended residual canopy cover following seed cut is 70-80%; large canopy gaps should be avoided. Site preparation is recommended to reduce litter thickness, facilitate moisture retention, increase surface soil temperature, and control competition. Once desirable regeneration is established, final overstory removal can be complete or partial. Even-aged rotations can range from 150-300 years. This even-aged system could potentially be adapted (i.e. irregular or group shelterwood) to manage uneven-aged stands of hemlock. Another alternative is applying the first step of a shelterwood and then converting to single-tree selection (Lorimer 1995).

Application of the single-tree selection system to manage uneven-aged hemlock stands appears to be a viable management alternative on appropriate sites where browsing pressure is not excessive (Lancaster 1985, Lorimer 1995, Goerlich and Nyland 2000, Kenefic and Seymour 2000, Ward and Smith 2000, Webster and Lorimer 2002, Webster and Lorimer 2005). It is more commonly applied in New England than in the Lake States. Success in applying uneven-aged systems has been variable; the primary barrier has been gap capture by sugar maple. In uneven-aged selection systems, regeneration is managed in canopy gaps. Because hemlock is very shade tolerant and grows in height more slowly than its competitors, canopies should be lightly thinned to approximately 90% crown closure to encourage the establishment of regeneration. Appropriate seed bed conditions, competition control, and site preparation needs and alternatives should be evaluated. Established regeneration is released in small gaps less than 40 feet in diameter, and then periodically re-released. During thinning and release operations, discriminate against sugar maple. Two uneven-aged stocking guides for hemlock dominated stands prescribe a residual basal area of 130 square feet per acre and a maximum diameter class of either 18 inches or 30 inches (Lancaster 1985, WDNR 1990). Recommended cutting cycles range from 10-20 years. The principle advantage of single tree selection is the opportunity to develop and maintain a mature and structurally diverse forest (Lorimer 1995, Webster and Lorimer 2002).

In all regeneration methods, site preparation needs to prepare appropriate seedbeds and control competition should be evaluated (Lancaster 1985, Goerlich and Nyland 2000). Site preparation can be implemented through partial mechanical scarification. The typical objective is to mix the mineral soil and humus or remove the litter layer and expose mineral soil over a portion of the ground surface. Site preparation should be implemented to coincide with a good seed crop.

Protection of hemlock regeneration from deer browsing is essential to successful establishment. Well-established advanced regeneration is at least 7-10 feet tall; above deer and able to compete (Kelty 1986, Goerlich and Nyland 2000). Where well-established regeneration has developed, overstory removal can be implemented to release young trees (Lancaster 1985, Goerlich and Nyland 2000). To regenerate even-aged or two-aged stands, overstory removal should probably proceed incrementally. Within uneven-aged systems, well established advanced regeneration can be released in gaps.

The most common silvicultural method applied to hemlock stands is thinning, following the standard even-aged stocking guide for hemlock (Tubbs 1977, Lancaster 1985). Thinning can favor hemlock and discriminate against hardwoods. However, thinning of mature stands must proceed incrementally, because excessive crown release can result in stress induced mortality of residual hemlock following logging (Graham 1941a, Lancaster 1985, Godman and Lancaster 1990). As a general guide, maintain crown closure at approximately 90% and release crowns only on 1-2 sides (Lanasa et al. 1995, Lorimer 1995). Periodic thinning can sometimes result in the development of advanced regeneration.

Passive management is a forest management alternative that does not include active silviculture. Some hemlock stands are passively managed to achieve specific management goals and objectives (e.g. old-growth, research, wildlife habitat, aesthetics), others because silvicultural results are uncertain or success unlikely (e.g. deer yards). Individual hemlock trees and small groves within hardwood stands provide excellent choices for long-term retention.

Disturbance – Natural and Human

Common disturbance events impacting modern hemlock forests include: wind and ice storms, drought, fire, insect and disease outbreaks, herbivory, and logging. Hemlock is shallow rooted, making it susceptible to windthrow, fire, drought, and logging damage (Lancaster 1985, Mladenoff and Stearns 1993). Wind has been a significant agent of natural disturbance in both historic and current hemlock forests. Wind events result in patchy and sporadic disturbance to hemlock stands and landscapes; canopy disruptions may range from minor to catastrophic. Drought is a serious damaging agent, especially during the seedling stage (Rogers 1978, Godman and Lancaster 1990, Parshall 1995, Peterson and Pickett 1995). Fire is an uncommon event in typically moist hemlock forests. Fire kills small hemlock trees. Older trees have thick bark and are somewhat resistant to light surface fires, but hot surface fires can cause root injury (Godman and Lancaster 1990). Deer browse hemlock, cause seedling mortality, and can limit hemlock regeneration success in areas with high deer populations. Logging often converts hemlock to hardwoods, and apparently often favors sugar maple (Eckstein 1980, Hix and Barnes 1984, Davis et al. 1994).

A significant threat to the future persistence of eastern hemlock forests is the exotic insect hemlock woody adelgid (*Adelgis tsugae*). It has caused extensive decline and mortality of hemlock in the eastern U.S.; eastern hemlock trees seem to have little resistance to attacks by this exotic insect. Currently, hemlock wooly adelgid primarily occurs in the Mid-Atlantic and Northeastern states, but it has also been found at isolated locations in northern New England and Michigan. It also occurs along the West Coast, but western hemlocks are much more resistant to damage.

Immigration, settlement, and land use by EuroAmericans have resulted in the most severe disturbance to local and regional vegetation during the Holocene (Foster and Zebryk 1993). Logging, land clearance, and agriculture transformed the landscape and altered forest composition, structure, and function. Many areas have reverted to forest, but the effects of large-scale disturbances in the late 1800's to early 1900's are pervasive and long-term; ecosystems have changed significantly and presettlement conditions cannot be entirely restored (Mladenoff and Howell 1980, Kelty 1986, Foster et al. 1992, Foster and Zebryk 1993, Mladenoff and Stearns 1993).

The representation of hemlock and yellow birch across northern WI landscapes has been dramatically reduced, while maples, basswood, aspen, and oak have increased (Eckstein 1980, Mladenoff and Howell 1980, Mladenoff and Stearns 1993). Hemlock was logged for timber and tannin. Fires killed older trees and regeneration. Land was cleared. Forest management sometimes discriminated against hemlock owing to its low timber value. Hemlock seed sources were lost in some areas. Coniferous litter and well rotted downed woody debris became less common. Maple and aspen forests exerted dominance and created ecosystems that favor hardwood maintenance and discourage successful hemlock establishment (Mladenoff and Stearns 1993). In cases where hemlock does establish, deer can be a barrier to survival. The resulting environment has not been conducive to widespread hemlock regeneration (Mladenoff and Howell 1980, Mladenoff and Stearns 1993). The current environment and disturbance regime in northern mesic forests favor dominance by sugar maple and aspen. However, developing and maintaining large patches of mature conifer dominated forests subjected to relatively infrequent light severity disturbance could perhaps foster the successful regeneration, recruitment, and maintenance of hemlock across landscapes (Foster and Zebryk 1993, Mladenoff and Stearns 1993).

<u>Geographic Distribution</u>

<u>Historic</u>

At 5000 years before present (BP), hemlock occurred in upper Michigan, but was a minor species. Hemlock expanded its range and invaded many stands and landscapes in upper Michigan and northern Wisconsin 3500 to 2500 years BP (Davis et al. 1998). This invasion has been associated with climate change that resulted in a moister climate and a regional rise in water tables (Davis et al. 1992, Davis et al. 1998). It is estimated that hemlock reached its current range limit about 1000 years BP (Davis et al. 1992).

In the Sylvania study by Davis et al. (1992, 1998), hemlock invasion at the stand level was not associated with disturbances, such as fire or catastrophic windthrow. Apparently, the moister climate enabled hemlock to reproduce within intact white pine forests and direct succession to a hemlock-white pine association. The moister climate and increased dominance by hemlock resulted in decreased frequency and severity of fire. Modern hemlock dominated stands developed mostly within the last 1500 years as white pine was eliminated from these systems. In some stands, particularly on some wetland and lake borders, infrequent light to moderate severity disturbances enabled white pine to persist in the hemlock-white pine association; here, white pine was not eliminated until the logging era. Hemlock and hemlock-white pine stands have apparently persisted on the same sites within Sylvania for over a millennium. Hemlock was less successful in invading mesic oak and mixed hardwood stands, many of which eventually developed into modern northern hardwood forests (mostly within last 1000 years). Just prior to Euro-American settlement, hemlock-hardwood landscapes were characterized by intermixed patchy stands dominated by hemlock-yellow birch and sugar maple-basswood.

At the time of Euro-American settlement (mid-1800's), about 60-70% of all closed forests in Wisconsin were hemlock or northern hardwood (Frelich 1995). Most of these forests were old and uneven-aged. Early developmental stages (i.e. stand initiation and stem exclusion) and early-successional species (*e.g*. aspen and white birch) typically comprised only 5-20% of the extensive hemlock-hardwood landscapes (Lorimer and Frelich 1994, Frelich 1995, Frelich 2002).

At the time of Euro-American settlement, the hemlock forest type occurred in northern Wisconsin (Province 212) where it was common (Figure 12-1) (Finley 1976, Schulte *et al*. 2002, Bolliger *et al*. 2004). Studies of characteristic vegetation occupying Wisconsin landscapes at this time generally do not clearly separate the hemlock and northern hardwood forest types. These two types together were predominant in most Sections (J, X, Q, T, Z) within Province 212 (Appendix A, Fig. A.2) covering northern Wisconsin. Hemlock was the species of greatest prominence throughout much of this area (Mladenoff 1995); however, it rarely occurred in the extreme northwest (Sections K, Y, and western Q). On glacial sediments in northern Wisconsin, characteristic associations were comprised of mixtures of hemlock, yellow birch, sugar maple, basswood, and beech (in eastern Wisconsin), with elm, red maple, balsam fir, and white pine as important associates. The abundance of hemlock, yellow birch, and elms has declined significantly since Euro-American settlement. Land use conversion, logging, and fires eliminated hemlock from much of the landscape and resulted in environments not conducive to widespread hemlock regeneration. Many of the sites formally occupied by hemlock have been converted to nonforest land uses or, if forested, to aspen or northern hardwoods. In southern Wisconsin (Province 222), hemlock was rare, due to the climate and fire regime that dominated the landscape.

<u>Current</u>

Hemlock reaches its range limits in western and central Wisconsin (Figure 12-1) (Godman and Lancaster 1990). Although once abundant, the hemlock forest type is now a minor cover type in northern Wisconsin (Figure 12-2) (Schmidt 1998). Within Province 212 in northern Wisconsin, hemlock is most common in the following Sections (Appendix A, Fig. A.2): X, J, T, Q (eastern ½), Y (eastern ½), I, and O; it was and is rare within the rest of Province 212. Within Province 222 in southern Wisconsin, the hemlock forest type was and is rare.

Summary data from Wisconsin's fifth statewide forest inventory and analysis (FIA 1993-1996) elucidates the following trends (Schmidt 1998, Kotar *et al*. 1999):

a. The hemlock forest type occupied approximately 121,000 acres of forest land statewide (<1% of forest land area). The type gained about 34,000 acres between 1983 and 1996.
b. Hemlock net growing stock volume accounted for about 2% of the statewide volume on forest land. Volume increased between 1983 and 1996.
c. The northeast survey unit was home to about 64% of the hemlock type statewide forest land area and 63% of the hemlock statewide volume. Here, the hemlock type comprised approximately 2% of the forest land area, and hemlock 5% of the volume.
d. Hemlock type forest land acreage was distributed among age classes as follows: 1-39 years contained 13% of acreage, 40-79 years had 21%, 80-119 years had 44%, and ≥120 years contained 22% of acreage. There were about 26,600 acres of hemlock forest land with a stand age class ≥120 years. However, the acreage in this oldest age class declined from the previous inventory (38,400 in 1983). Acreage also decreased in the 1-39 year age class, but increased in 40-119 year classes.
e. Hemlock volume was distributed among diameter classes as follows: 5-11 inches contained 21% of volume, 11-21 inches had 60%, and ≥21 inches with 19% of volume.

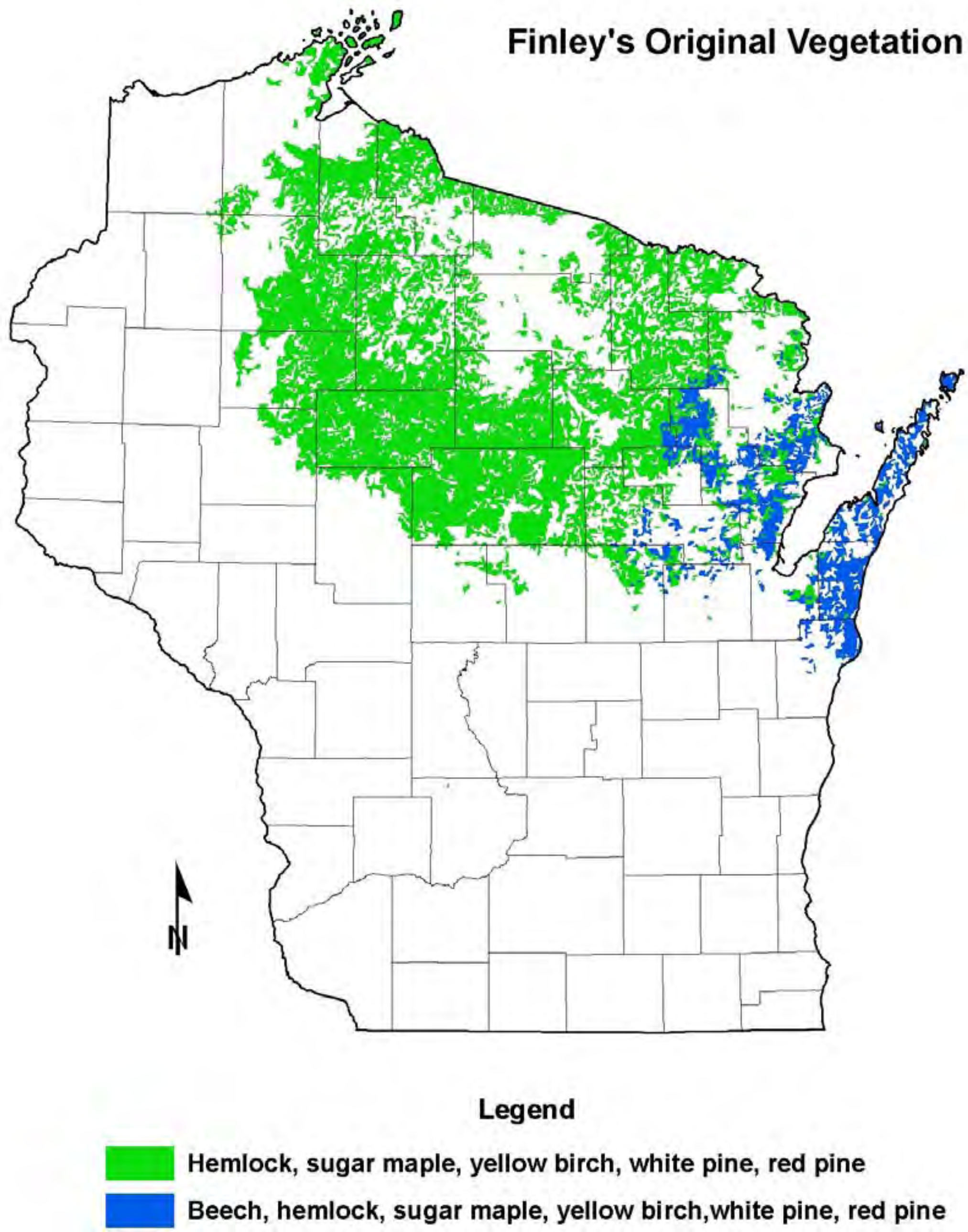


Figure 12-1. Historic statewide distribution of hemlock-hardwood forest cover type from *Original Vegetation Cover of Wisconson* by R.W. Finley (1976).

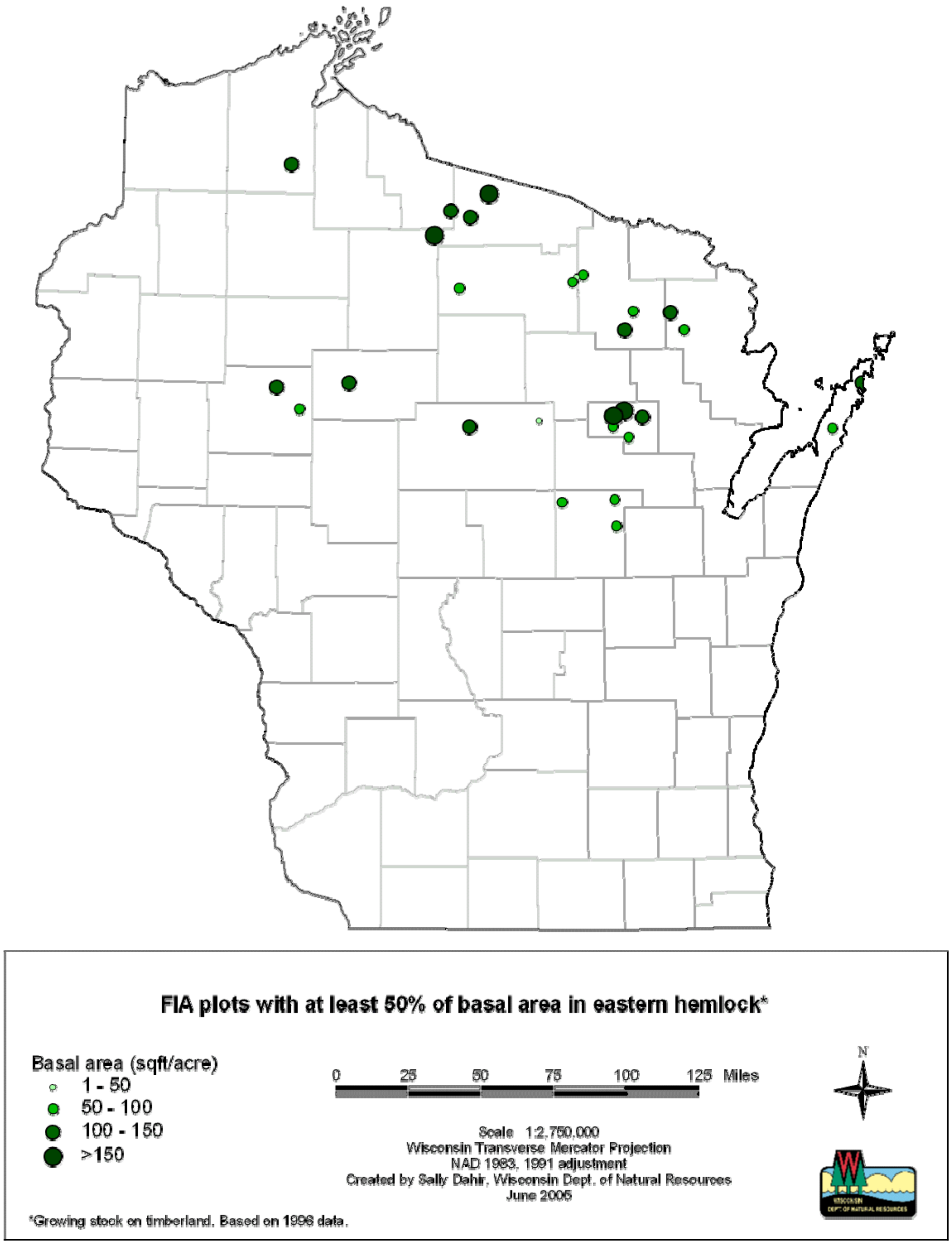


Figure 12-2. Indication of current statewide distribution of hemlock forest cover type, from 1996 Wisconsin Forest Inventory and Analysis (FIA).
Map prepared by S. Dahir (2005 unpublished).

ECOLOGICAL CHARACTERISTICS OF RELICT AND OLD-GROWTH FORESTS

See Chapter 11 – Northern Hardwood; the northern hardwood and hemlock cover types are similar and often intermingled (i.e. hemlock-hardwood).

Old-growth Forest Conditions Begin

Old, multi-aged, unmanaged hemlock communities have many age and size classes of trees, including numerous old and large trees, and an uneven canopy. There are few or no remnants left from the original cohort that initiated stand development following catastrophic disturbance. Canopy replacement occurs principally through gap dynamics. Most stands will exhibit non-equilibrium age structure reflecting episodic recruitment of new age classes into the canopy (Willis and Coffman 1975, Foster 1988, Frelich and Lorimer 1991, Lorimer 1995, Loucks and Nighswander 2000, Woods 2000a and 2000b, Ziegler 2000, Frelich 2002, D'Amato and Orwig 2008). Although uncommon, a shifting-mosaic steady state can be attained if developmental processes and light severity disturbance maintain consistent low rates of tree mortality (Frelich and Graumlich 1994, Frelich 1995, Lorimer 1995, Dahir and Lorimer 1996, Woods 2000, Frelich 2002, Ziegler 2002). In a strict sense, under natural conditions, 300-400 years without significant exogenous disturbance are required to reach this state. However, within this period, the occurrence of a moderate disturbance event that significantly impacts the canopy and alters stand age structure can be expected. In old-growth hemlock forests, large diameter, standing and downed coarse woody debris, in all decay classes is present.

In practice, old-growth conditions begin when overstory trees become relatively old and large, mortality of large overstory trees is becoming significant, canopy gaps are present, large coarse woody debris is accumulating, and stands either are or are becoming uneven-aged. Typically, these stands will be in the transition stage of stand development. The specific age threshold is identified as designation criteria B: at least 20% of stand basal area comprised of trees at least 210 years old. Typically, these stands will contain some trees greater than 20 inches DBH.

Natural Disturbance Regimes

Within hemlock-hardwood landscapes, natural disturbances generally operate in a heterogeneous manner, resulting in episodic pulses of mortality and regeneration. Light severity disturbances are relatively frequent. Moderate severity disturbances tend to be infrequent and irregular, but have significant impacts on forest composition and structure. Catastrophic disturbances of hemlock forests are rare. Light to moderate severity disturbances occur relatively frequently at small spatial scales, whereas catastrophic disturbances act infrequently on a large scale (Dunn 1983, Canham and Loucks 1984, Foster 1988, Frelich and Lorimer 1991, Tyrrell and Crow 1994a, Loucks and Nighswander 2000, Woods 2000a, Frelich 2002, Ziegler 2002, Ruffner and Abrams 2003, D'Amato and Orwig 2008). Common historical natural disturbance agents were wind and ice storms, drought, fire, and insects and disease (Stearns 1951, Foster and Zebryk 1993).

Windthrow is the principle agent of exogenous disturbance in hemlock forests (Darlington 1930, Stearns 1949, Frelich 1995, Tyrrell et al. 1998, Frelich 2002, Zieglar 2002, Ruffner and Abrams 2003). Light to moderate severity windthrow reduces canopy density and enables regeneration and canopy recruitment. Tip-up mounds and windthrown trees (aka nurse logs) provide sites that facilitate the regeneration of hemlock and yellow birch (Willis and Coffman 1975, Tyrrell et al. 1998). Canopy gaps are usually captured by the release of suppressed trees, but larger gaps, especially those created following moderate severity disturbance events, are sometimes captured by newly established less tolerant and faster growing associates. Windthrow tends to be more frequent and more severe in specific physiographic locations and where soil characteristics limit rooting depth.

Some old-growth hemlock forests have persisted for centuries subjected only to light severity disturbances resulting primarily from senescence and windthrow. Disturbance and canopy turnover may be relatively frequent and regular, or more irregular and episodic. Light severity disturbance enables both the initiation of regeneration and the release of suppressed hemlock trees. Hemlock stands greater than 300 years old usually exhibit a wide range of tree ages and long-term self-replacement through gap dynamics and low intensity disturbance (Tyrrell and Crow 1994a, Lorimer 1995, Woods 2000a, Ziegler 2002, Ruffner and Abrams 2003, Busing 2005). More severe exogenous disturbance is not required to regenerate and maintain hemlock stands (Lorimer 1995, Dahir and Lorimer 1996, Davis et al. 1998, Woods 2000a and 2000b, Lorimer et al. 2001, Ziegler 2002).

Moderate severity disturbances to hemlock ecosystems have significant cumulative impacts on stand structure and create complex multi-aged stands (Frelich 2002, Hanson and Lorimer 2007). Moderate disturbances result in pulses of regeneration and release, and the development of several distinct age cohorts (Willis and Coffman 1975, Foster 1988, Tyrrell and Crow 1994a, Lorimer 1995, Loucks and Nighswander 2000, Woods 2000a, Frelich 2002, Ruffner and Abrams 2003, D'Amato and Orwig 2008). Depending on disturbance type and timing, as well as site and stand characteristics, these moderate disturbances can enable either compositional stability or variability. Moderate severity disturbance can facilitate both the release of suppressed trees that developed following previous light severity disturbance events and the initiation of new regeneration (Willis and Coffman 1975, Hibbs 1982, Foster 1988, Lorimer 1995, Loucks and Nighswander 2000, Woods 2000a, Ruffner and Abrams 2003). For example, wind events that remove a third of the canopy in an irregular patchy pattern can release suppressed hemlock trees and regeneration. Alternatively, if advanced regeneration is scarce and seed sources available, associates, such as white pine, birches, and maples, can capture some gaps. If a ground fire follows windthrow, either hemlock or other associates can seed-in and establish regeneration cohorts, depending on stand and site factors such as seed sources, annual seed crops, and precipitation.

In Sylvania, Frelich and Graumlich (1994) and Parshall (1995) discovered that canopy turnover rates averaged 5.4% per decade; the maximums observed were 11-35% in one decade. Light severity disturbances created small gaps, resulting in 2-12% canopy removal during most decades. Less regular disturbances that removed 10-20% of the canopy were important to the recruitment of new cohorts. The pattern was one of repeated light severity disturbances scattered across the stand, and indicated a stable disturbance regime (Frelich and Graumlich 1994).

In another study in the Porcupine Mountains (Dahir and Lorimer 1996, Lorimer et al. 2001), the old-growth hemlock annual gap formation rate was 0.58%, which was much less than for sugar maple (0.85%). Canopy turnover times averaged 192 years for hemlock old-growth and 128 years for sugar maple old-growth. Moderate severity disturbances of hemlock-hardwood forests removed 30-50% of the canopy every 200-400 years (Frelich and Lorimer 1991, Lorimer 1995, Lorimer et al. 2001).

In the Adirondacks, N.Y., Ziegler (2002) discovered that old-growth hemlock gap formation rate was 4.8-5.4% per decade. Averages across stands and time were fairly stable. At the stand level, disturbances tended to be more variable and episodic, with both active and quiescent periods.

In Massachusetts, D'Amato and Orwig (2008) documented disturbance regimes in old-growth hemlock-hardwoods forests as dominated by relatively frequent, low-intensity disturbances that averaged 5% canopy area disturbed per decade. Most decadal disturbances resulted in less than 10% canopy loss, and the maximum decadal canopy disturbance was 26%. Small scale disturbances appeared to operate somewhat randomly on the landscape. Broader scale disturbances resulted in regeneration recruitment peaks in disparate patches across landscapes.

Although infrequent, moderate to severe disturbances can facilitate the maintenance of long-lived yellow birch and white pine as associates (Hanson and Lorimer 2007). Windthrow, drought, and fire can interact, exposing mineral soil and increasing light levels in large gaps, forest openings, or across stands. These conditions appear to be most prevalent along lake and swamp edges, ridge tops, and steep slopes (Stearns 1951, Ruffner and Abrams 2003).

In hemlock forests, catastrophic disturbances are rare (Dunn 1983, Canham and Loucks 1984, Frelich and Lorimer 19991, Tyrrell and Crow 1994a, Frelich 1995, Mladenoff 1995, Loucks and Nighswander 2000, Woods 2000a, Frelich 2002). The return interval for catastrophic wind and fire events can range from 1000 to more than 4000 years. Sometimes, hemlock can reassert dominance following severe disturbance (Kelty 1986). Most even-aged hemlock stands originated following fire or severe windthrow followed by fire (Miles and Smith 1960, Eckstein 1980, Tyrrell and Crow 1994a, Woods 2000a). However, catastrophic disturbance of hemlock stands often results in conversion to other forest types (e.g. aspen-white birch, white pine, northern hardwood).

Hemlock forests tend to be moist and cool, and thus fire resistant (Foster and Zebryk 1993, Tyrrell et al. 1998, Frelich 2002). Ground fires apparently are infrequent and catastrophic fires are rare. Hemlock is fire sensitive, and generally declines as fires become more frequent or catastrophic (Foster and Zebryk 1993).

In the eastern U.S., presettlement Holocene hemlock populations fluctuated over millennia in response to climate and disturbance (Foster and Zebryk 1993). Following declines, hemlock has generally been able to reassert dominance within 300-1200 years. If climate is compatible and disturbance is relatively infrequent and light severity, then hemlock has a competitive advantage, owing to its shade tolerance and long lifespan.

Tree and Stand Age

Most old, unmanaged hemlock stands are uneven-aged (Rogers 1978, Frelich 1995, Lorimer 1995, Loucks and Nighswander 2000, Ziegler 2002, Frelich 2002). Age distributions tend to be irregular within and between stands.

Within most old-growth hemlock stands, most canopy trees are within the age range of 100-400 years. Age data collected in old, unmanaged hemlock stands in the Lake States include:

- In a compendium of old, unmanaged hemlock stands measured in Wisconsin and Michigan, the average age of hemlock trees ranged from 150 to 265 years. Across all stands, the average age was 205 years. Maximum ages measured ranged from 177 to 530 years (Tyrrell et al. 1998).
- In a series of old, unmanaged hemlock stands measured in western upper Michigan and northeastern Wisconsin, Lorimer et al. (2001) determined that most stands were uneven-aged with an irregular age distribution. Most canopy trees were 200 to 350 years old; the oldest hemlock tree measured was 513 years old.
- In Sylvania, Michigan, Frelich and Graumlich (1994) determined that most stands were old and uneven-aged, with more than 250 years since any catastrophic disturbance. Trees of a given cohort were often well dispersed throughout the stand.
- In the Huron Mountains and Dukes Research Natural Area, Michigan, Woods (2000a and 2000b) determined that most stands were uneven-aged. Hemlock age distribution was relatively regular, but yellow birch occurred in even-aged cohorts. In hemlock dominated forests, most canopy trees were 150-400 years old.
- In the Huron Mountains, Michigan, Willis and Coffman (1975) determined that most stands were uneven-aged with an irregular age distribution. However, yellow birch occurred in even-aged patches and cohorts. Average tree ages were: 140 years for hemlock, 172 years for yellow birch, and 226 years for sugar maple.
- In the Porcupine Mountains, Michigan, Darlington (1930) determined that most hemlock stands were uneven-aged and most canopy trees were 100-400 years old.

Estimates of average canopy residence time (mean time since release) for hemlock trees in old-growth hemlock-hardwood stands in the Lake States often range from 150-200 years (Frelich and Lorimer 1991, Frelich and Graumlich 1994, Parshall 1995, Dahir and Lorimer 1996, Frelich 2002); similarly, in the Adirondacks, average canopy residence times for old-growth hemlock were 184-211 years. Estimates of average age and size at time of death for hemlock canopy trees range from 235-300 years and 20-26 inches DBH (Lorimer 1995, Dahir and Lorimer 1996, Lorimer *et al*. 2001). Many trees live beyond these average mortality values.

In old, unmanaged hemlock-hardwood stands, documented mortality rates were comparatively low for medium sized trees, but high for saplings and large trees (Eckstein 1980, Woods 2000a, Lorimer *et al.* 2001, Busing 2005). The mean annual mortality rate was only 0.3% for hemlock trees 7-26 inches DBH. For trees 5 to 24 inches DBH, mean annual mortality rates were 0.5% for hemlock and 1.0% for sugar maple. However, for shade tolerant trees larger than 26 inches DBH, hemlock annual mortality rates increased sharply and averaged 1.5-2.9% (Lorimer *et al*. 2001).

A gap-maker is a relatively large-crowned canopy tree that dies. Most gap-makers die standing, eventually breaking off at a variety of heights (becoming snags), some trees are uprooted, and many show evidence of substantial decay (Tyrrell and Crow 1994b, Dahir and Lorimer 1996, Lorimer *et al.* 2001, Busing 2005). Some gap-makers are probably approaching senescence, whereas others are succumbing to competitive stress.

Succession and Stand Structural Development

Compositional change (succession)

As a potential climax community type defined by a shade tolerant tree species, established hemlock stands are expected to progress through structural development and succession with relatively little change in overall species composition. Mortality of individual trees and small groups from senescence or minor disturbance will facilitate a shift to the most tolerant species (i.e. hemlock, sugar maple, beech). Typically, hemlock regeneration is established following minor canopy disturbance and then released following later disturbance. Hemlock regeneration tends to be patchy and initiation often episodic. Repeated episodes of small gap release followed by suppression can favor the slow ascension of hemlock into the canopy. However, moderate disturbance with gap and patch recruitment can result in either hemlock maintenance or increased representation of other tolerant and mid-tolerant species (e.g. yellow birch, beech, sugar maple, red maple, basswood, ashes, elms, ironwood, balsam fir, white spruce, and white pine), and even some patches of intolerant species (*e.g.* aspen and white birch). Small spot fires and ground fires can facilitate the regeneration of hemlock, but can also enable the maintenance of small patches of mid-tolerants and intolerants. Catastrophic disturbance can result in regeneration of the hemlock type (*e.g*. blowdown, followed by fire, followed by a moist climatic period) or conversion to an early- to mid-successional composition (*e.g*. fire that creates a mineral soil seedbed can facilitate aspen – white birch or white pine regeneration). Early- to mid-successional communities will usually be replaced through relay floristics or gap replacement by another community. Actual specific stand and landscape successional processes are complex. Major factors influencing composition following disturbance are: disturbance type, timing, and severity; community composition; seed source availability and seed bank; seedbed condition; sprouting ability; and other climatic and site factors (Darlington 1930, Graham 1941a, Stearns 1949 and 1951, Willis and Coffman 1975, Kelty 1986, Foster and Zebryk 1993, Frelich and Graumlich 1994, Tyrrell and Crow 1994a, Peterson and Pickett 1995, Tyrrell *et al.* 1998, Woods 2000a and 2000b, Ziegler 2000, Lorimer 2001, Frelich 2002, Ziegler 2002, Ruffner and Abrams 2003).

Hemlock and sugar maple are two associated late-successional dominants. Although intermingled, these two communities have been able to occupy sites and exclude each other for long periods of time (Frelich et al. 1993, Davis et al. 1994, Davis et al. 1998, Woods 2000a). Dense hemlock stands influence energy and nutrient dynamics through impacts on microclimate, groundflora, humus type and thickness, and soil development (of chemical, physical, and biological properties) (Rogers 1978, Frelich et al. 1993, Davis et al. 1994, Mladenoff 1995). Hemlock stands develop environmental conditions that discourage sugar maple (Rogers 1978, Davis et al.1994, Davis et al. 1998). Similarly, sugar maple stands perpetuate conditions (e.g. litter) that discourage hemlock regeneration. "Positive neighborhood feedbacks on recruitment appear to reinforce the continued dominance of hemlock and sugar maple in their respective patches" (Frelich et al. 1993, Davis et al. 1998).

Canopy gaps are created when overstory trees die. Small gaps often are filled through crown expansion of adjacent canopy trees, but sometimes are captured by ascension of suppressed trees. Large gaps are eventually filled by a tree(s) that competitively captures the vacated growing space and ascends into the canopy. Gaps can be captured by previously suppressed shade tolerant trees or by freshly regenerated, rapidly growing, mid-tolerant to intolerant trees. In hemlock-hardwood forests, gaps usually are captured by previously suppressed shade tolerant trees ranging in age from 20-200 years (Dahir and Lorimer 1996, Ziegler 2002). Hemlock trees that are released and then ascend into the canopy typically range in age from 90-220 years and from 3-17 inches DBH (Dahir and Lorimer 1996). Once released, it may take 35-50 years or more for hemlock trees to ascend into and become codominant within the canopy (Webster and Lorimer 2004).

In a study of hemlock-hardwood old-growth in the Porcupine Mountains, in hemlock stands, hemlock and sugar maple each captured about 40% of modern gaps, with other hardwoods, such as yellow birch, red maple, and ashes, capturing the remaining 20% (Dahir and Lorimer 1996). Hemlock was most successful in capturing very small gaps, 400 square feet and less (Dahir and Lorimer 1996). Several episodes of release in small gaps followed by suppression through canopy expansion can favor eventual hemlock canopy ascension (Lorimer 1995). The mid-tolerant hardwoods usually required larger gaps, and were most often successful in gaps larger than 850-1000 square feet (Dahir and Lorimer 1996, Webster and Lorimer 2005). Sugar maple demonstrated success in all gap sizes. In contrast to pre-historical conditions, hemlock regeneration in the 20th century appears to be insufficient to maintain long-term stand dominance (Dahir and Lorimer 1996).

In another study of hemlock old-growth, Tyrrell and Crow (1994a) observed that the density and distribution of hemlock regeneration is highly variable. The amount of hemlock regeneration (seedlings and saplings) was not correlated to stand age, area of canopy gaps, or volume of coarse woody debris. They surmised that deer browsing may prevent recruitment into younger size classes.

Tree and Stand Growth Rates

Tree growth rates are highly variable, depending on available moisture, nutrients, and energy, as well as tree anatomy, physiology, genetics, and health. Hemlock is a slow growing, long lived, shade tolerant tree species. If other factors, such as available moisture, are not limiting, a hemlock tree will grow most rapidly in near full sunlight. Healthy canopy trees with large crowns tend to grow most rapidly.

Hemlock can tolerate prolonged suppression, surviving in deep shade with minimal growth for a century or two, and then respond, through accelerated growth, to canopy release (Hough 1965, Rogers 1978, Eckstein 1980, Godman and Lancaster 1990, Foster and Zebryk 1993, Mladenoff and Stearns 1993, Anderson and Gordon 1994, Lorimer 1995, Tubbs 1995, Dahir and Lorimer 1996, Woods 2000a, Lorimer et al. 2001). Under typical conditions in old-growth forests, hemlock requires 27-35 years to reach breast height (Tyrrell and Crow 1994a). Trees 1 inch DBH at 100 years and 3 inches DBH at 200 years are not uncommon. Because of slow growth and extreme shade tolerance, similarly aged trees may be of very different sizes; for example, one 300 year old tree may be 10 inches DBH while another may be 30 inches DBH (Eckstein 1980, Godman and Lancaster 1990). Tree diameter is not a good predictor of age (Stearns 1951, Tyrrell and Crow 1994a, Kenefic and Seymour 2000, Ziegler 2000).

Old-growth stands tend to produce and maintain high levels of woody biomass. The concept of equilibrium in old-growth implies that net growth in stem volume and woody biomass is near zero (or fluctuates about a mean); growth and mortality are balanced.

Stand Structural Development

Old-growth hemlock stands generally will be in the later stages of stand development. They are the products of stand maturation and senescence. Representative developmental stages are demographic transition and multi-aged (Frelich 2002). In hemlock, these two stages can be difficult to differentiate based on tree size and age distributions (Frelich 1995, Frelich 2000). These stages are characterized by the development of significant structural characteristics, including: uneven-aged, relatively old and large trees, broken canopy with gaps, the accumulation of large diameter coarse woody debris, and high vertical and horizontal diversity.

During demographic transition in hemlock-hardwood forests, the onset of significant mortality among dominant large-crowned canopy trees creates relatively large canopy gaps (0.01-0.1 acres). Mortality is typically caused by processes related to tree senescence or by light severity exogenous disturbance. However, these stands are dominated by large old trees that are susceptible to disturbance of medium severity. New cohorts enter the canopy through gap dynamics, resulting in a transition from even-aged to uneven-aged structure. Depending on initial composition, a shift in species composition to more tolerant species can occur.

Hemlock stands typically exhibit demographic transition and early development of old-growth conditions around 180-300 years of age (Tyrrell and Crow 1994a, Lorimer et al. 2001). As hemlock stands reach the end of the stem exclusion stage and begin demographic transition, maximum basal areas are developed (Tyrrell and Crow 1994a). The number and basal area of trees 20 inches DBH and larger increases and reaches a maximum, but there are few trees 28 inches DBH and larger (Tyrrell and Crow 1994a). As demographic transition progresses, hemlock stands become increasingly uneven-aged (Tyrrell and Crow 1994a).

Hemlock stands typically enter the multi-aged stage of stand development around 250-300 years of age (Tyrrell and Crow 1993, Tyrrell and Crow 1994a, Lorimer et al. 2001). Much of the original post-disturbance even-aged cohort will have been eliminated. These uneven-aged stands are composed of irregular patches of trees of varying size and age. The diameter to age distribution is characterized by few trees in many size classes (Tyrrell and Crow 1994a). Multi-aged stands usually contain some trees older than 300 years. These stands often exhibit the greatest number and basal area of trees 28 inches DBH and larger (Tyrrell and Crow 1994a). Downed hemlock logs are present in all decay classes, including very decayed, collapsed logs. Canopy gap dynamics result in the regeneration and ascension of new age classes. Canopy gaps typically are caused by processes related to tree senescence and by irregular, light severity disturbance. Medium severity disturbances occur infrequently, but can have significant long-term effects on stand composition and structure. Within multi-aged hemlock stands, changes in species composition tend to occur slowly. The multi-aged condition will persist until a catastrophic disturbance levels the canopy and reinitiates stand development.

Within Wisconsin, the hemlock cover type offers the potential to develop old-growth stands and landscapes that are dominated by large old trees, and that are relatively stable in composition and structure. However, significant uncertainties exist concerning the potential for hemlock to regenerate and maintain dominance under current and future environmental conditions.

Tree Size Distribution

In old, undisturbed, uneven-aged hemlock-hardwood stands, size class distribution typically is uneven and irregular. Within these stands, typical mean overstory diameters range around 20 inches, with trees greater than 18 inches diameter occupying about one-half of the canopy area, trees 10-18 inches diameter occupying another third, and the remainder occupied by gap saplings and poles (Lorimer and Frelich 1994, Ziegler 2000). In old-growth hemlock stands, there is usually significant basal area in trees 20 inches DBH and larger; stands in advanced developmental stages on good sites often exhibit significant representation of trees 28 inches DBH and larger (Tyrrell and Crow 1994a, Ziegler 2000). The maximum diameter of hemlock trees in old-growth stands typically is 28-40 inches, but can range from 15-50 inches (Rogers 1978, Godman and Lancaster 1990, Tyrrell *et al.* 1998).

Stand Density

The following table summarizes the range of stand densities measured in many different old, undisturbed, hemlock stands in Wisconsin and Michigan (from Tyrrell et al. 1998, conifer-northern hardwood forests, hemlock-dominated). Stand density is highly variable. Average basal area for all trees 4 inches DBH and larger is 208 square feet per acre, and the range is 128 to 279 square feet per acre. If additional studies from the northeast are include, the range becomes 104 to 644 square feet per acre.

DBH size class (inches)	Basal area (square feet / acre)
≥ 4	128 – 279
≥ 20	7 – 107
≥ 28	0 – 59

Canopy Stratification

Multilayered canopies that are highly irregular in terms of gap age and gap size are characteristic of old unmanaged stands. Variations in the size of trees and canopy gaps create a complex canopy structure.

Canopy Gap Size and Distribution

Based on 25 old, undisturbed stands measured in Wisconsin and Michigan, the portion of stands in canopy gaps ranged from 2 to 17%, with an average of 8% canopy gaps (Tyrrell et al. 1998).

In a study of a series of old-growth hemlock stands in Wisconsin and Michigan, Tyrrell and Crow (1994a) discovered that “canopy gaps occupied from 3.1 to 16.9% of stand area; the percentage increased significantly with increasing stand age.” Younger stands generally had less than 10%, whereas older stands often had greater than 10% of stand area in canopy gaps. Also, average gap size increased with stand age, ranging from 130 to 1300 square feet; the oldest stands had an average gap size of 540 square feet or larger, and occasional gaps greater than 2150 square feet. Gaps were usually created by the death of 2-4 trees. In older stands, gap-makers had larger crowns and therefore made larger gaps.

In another study of old-growth hemlock stands in the Porcupine Mountains, Dahir and Lorimer (1996) discovered that 82% of canopy gaps were created by single trees. The mean area of gaps at time of formation was 400-500 square feet.

Cavity Trees and Coarse Woody Debris

Large living cavity trees and large coarse woody debris (standing snags and downed wood) are abundant in old, undisturbed hemlock-hardwood forests (Tyrrell and Crow 1994b, Goodburn and Lorimer 1998, Ziegler 2000, Busing 2005). These structural attributes are more abundant in old, unmanaged stands than in managed stands (Goodburn and Lorimer 1998, Ziegler 2000). In old hemlock stands, the volume of coarse woody debris increases with stand age (Tyrrell and Crow 1994a, Ziegler 2000). The oldest hemlock stands can have volumes of 1150-2150 cubic feet per acre of dead wood (Tyrrell and Crow 1994a and 1994b).

As mature-to-old unmanaged hemlock stands become old-growth, total snag density, basal area, and volume can decrease with stand age, because shorter lived associated species are gradually eliminated; however, although the number of hemlock snags also decreases, hemlock snag basal area and volume increase (Tyrrell and Crow 1994a). Old, undisturbed hemlock stands measured in Wisconsin and Michigan exhibited the following snag densities:

- average 30 (range 14-73) snags per acre ≥4 inches DBH (Tyrrell et al. 1998)
    - — average 16 snags per acre ≥12 inches DBH (Goodburn and Lorimer 1998)
    - — average 11 large snags per acre ≥18 inches DBH (Goodburn and Lorimer 1998)
- average 25 (range 4-50) square feet per acre of basal area for snags ≥4 inches DBH (Tyrrell et al. 1998)

In old-growth stands, average snag DBH is about 15 inches (Goodburn and Lorimer 1998).

Old, undisturbed hemlock stands measured in Wisconsin and Michigan averaged 780 (range 160-1600) cubic feet per acre of volume for downed woody debris ≥8 inches diameter (Tyrrell et al. 1998). The volume of downed woody debris, particularly hemlock logs, increases with stand age (Tyrrell and Crow 1994a). Well decayed hemlock logs mostly occur in stands older than 250 years old (Tyrrell and Crow 1994a). Tyrrell and Crow (1994b) estimated that it takes nearly 200 years for hemlock logs to lose structural integrity and become partially incorporated into the soil. Stands 300 years of age and older have logs in all decay classes, log volumes of at least 900 cubic feet per acre, and dead wood volumes of at least 1140 cubic feet per acre (Tyrrell and Crow 1994a and 1994b). By about 350 years of age, hemlock forests may reach "dead wood equilibrium in which rates of log production from mortality balance rates of wood loss by decay" (Tyrrell and Crow 1994b).

Pit and Mound Microtopography

Pit and mound microtopography is characteristic of old hemlock forests (Darlington 1930, Willis and Coffman 1975, Tyrrell et al. 1998). Larger and older trees generally are more susceptible to uprooting than are smaller and younger trees (Frelich and Lorimer 1991, Frelich 2002). In general, old-growth hemlock forests can be expected to be more susceptible to tree uprooting and most likely to develop relatively extensive pit and mound microtopography over the long-term. Tyrrell and Crow (1994a) found that mounds occupied an average of 2.9% (0.4-8.0%) of the forest floor; however, within and between old, undisturbed hemlock stands, there was no correlation between stand age and the area occupied by mounds.

Young mounds with exposed bare mineral soil or thin litter, and old well rotted downed tree trunks provide germination microsites that can favor the regeneration of hemlock and yellow birch (Goder 1961, Willis and Coffman 1975, Rogers 1978, Godman and Lancaster 1990, Frelich et al. 1993, Mladenoff and Stearns 1993, Lorimer 1995, Tubbs 1995, Davis et al. 1998, Tyrrell et al. 1998). Pit and mound microtopograhy creates spatial heterogeneity (patchiness) of environmental conditions and can enhance plant species diversity.

Understory (shrubs and herbs) Composition and Spatial Structure

Hemlock stands tend to have a thick duff layer and a very dense canopy that provides deep shade (Willis and Coffman 1975, Godman and Lancaster 1990). Dense hemlock stands influence energy and nutrient dynamics through impacts on microclimate, humus type and thickness, soil development, and groundflora (Rogers 1978, Frelich et al. 1993, Davis et al. 1994, Mladenoff 1995). Typical understories are sparse in terms of composition and coverage (Darlington 1930, Willis and Coffman 1975, Godman and Lancaster 1990, Tyrrell et al. 1998). However, as old, multi-aged conditions develop, within stand vertical and horizontal diversity can increase; stand structural attributes that can foster spatial heterogeneity include: uneven-aged with relatively old and large trees, complex irregular multilayered canopies with increased area in gaps and increased range in gap sizes and ages; large downed woody debris, and pit an mound microtopography. Spatial heterogeneity of environmental conditions can enhance plant species diversity.

Ecosystem Benefits

In much of northern Wisconsin, hemlock (mostly old-growth) was a predominant forest community type for millennia. Many plant and animal species adapted to the characteristic habitats and niches provided. Hemlock forests exert control on the stand environment, and provide unique structures owing to the tree's shade tolerance and crown architecture. These forests and the unique habitat they provide have become uncommon in Wisconsin; old-growth has become rare.

Hemlock forests provide habitat preferred by some wildlife species (Eckstein 1980, Godman and Lancaster 1990, Wydeven and Hay 1995). Mammals that find preferred habitat in hemlock forests include: American marten, porcupine, red squirrel, red-backed vole, woodland deer mouse, and white-tailed deer (Wydevan and Hay 1995). Stand level structural attributes that provide habitat benefits include closed canopies (≥75% crown closure), large cavity trees, large snags, and large downed woody debris (Wydeven and Hay 1995). Large coarse woody debris is particularly important to maintaining habitat for marten and amphibians (Wydeven and Hay 1995). Large blocks of mature, closed canopy hemlock forest can provide benefits at the landscape level (Wydeven and Hay 1995).

Hemlock forests provide habitat preferred by some bird species. Birds that find preferred habitat in hemlock forests include: Black-throated Green Warbler, Blackburnian Warbler, Winter Wren, Red-breasted Nuthatch, and Solitary Vireo (Howe and Mossman 1995). Hemlock forests often support bird communities that exhibit high species richness, and uneven-aged hemlock forests support increased species richness and larger populations than do even-aged forests (Howe and Mossman 1995). Important habitat features include: dense shade that maintains a cool and moist environment, dense evergreen foliage, and vertical structure created by tolerant lower branches and suppressed trees.

Old-growth hemlock forests provide unique wildlife habitat (Mladenoff 1995). Old-growth hemlock forests are uneven-aged and exhibit complex structures that provide additional habitat features preferred by some mammals, birds, and amphibians, including: increased representation of large trees with large crowns and rough irregular bark; increased representation of large cavity trees, large snags, and large downed woody debris; and increased patchiness and habitat heterogeneity (Tyrrell and Crow 1994a, Tyrrell and Crow 1994b, Howe and Mossman 1995, Wydeven and Hay 1995, Goodburn and Lorimer 1998). Old-growth hemlock forests tend to support high bird densities, high species richness, and distinct assemblages (Howe and Mossman 1995). Increased spatial heterogeneity of environmental conditions (niches) can enhance biological diversity.

Hemlock forests apparently can modify stream environments and influence within stream biodiversity (Lemarie et al. 2000). The composition of invertebrate and fish communities is different in streams that drain hemlock forests as compared to hardwood forests. These stream ecosystems appear to function differently. Old-growth hemlock forests can impact some within stream structural development and also influence biodiversity.

ECOLOGICAL CHARACTERISTICS OF OLD FORESTS

Old forest conditions begin when trees are older and larger than normally managed for. This threshold is identified as designation criterion "C" and specifies "at least 20% of stand basal area comprised of trees at least 150 years old." These stands can be even-aged or uneven-aged. Old forests may experience relatively frequent low to moderate intensity disturbances of either natural or human origin.

Hemlock old forest stands typically will be in the late stem exclusion or the transition (natural or modified) stages of stand development. This is a period of structural instability, changing from a mature even-aged to an old even-aged to a multi-aged condition. In natural systems, there is a relatively high potential for episodic disturbance. Forest management can utilize light to moderate intensity disturbance to direct compositional and structural change.

The development of ecological characteristics and benefits will depend on the management class assigned and the management strategy applied (see Management Considerations for Managed and Extended Rotation Management Classes). Old forests – reserved will develop into old-growth. Old forests – managed could develop into old-growth or be maintained as old forest, depending on management objectives and success of applied silviculture. Those perpetuated as managed forest should exhibit many characteristics and benefits associated with old-growth. The inclusion of human disturbance will result in somewhat more regulated and perhaps more homogeneous conditions, and a somewhat younger and perhaps less structurally complex forest. Old forests – extended rotation will be maintained in an uneven-aged old forest condition, with compositional and structural characteristics intermediate between old-growth and younger managed forests. Extended rotation forests could provide many characteristics and benefits associated with old-growth, but would be more regulated, more homogeneous, younger, and less structurally complex.

MANAGEMENT CONSIDERATIONS FOR RESERVED MANAGEMENT CLASS

Reserved forests are designated based on disturbance history, structural characteristics, and management goals and commitments. Reserved forest can contain any of the ecological classes: relict forest, old-growth forest, and old forest. Designated stands and landscapes are protected and relatively undisturbed by humans. Therefore, these exhibit, or potentially will exhibit, maximum old-growth characteristics. Typically, they will contain old and large trees for the species and site represented. They will have, or will develop, an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. These forests may represent the classic concept of the old growth climax hemlock forest.

Hemlock ecosystems are dominated by shade tolerant species, but mid-tolerants may be common associates, and intolerant patches may occur. In reserved forest, successional and developmental processes modified by natural disturbance will determine compositional and structural change, although some indirect human influence and disturbance are unavoidable. In general, relatively stable late-successional associations are expected to develop, with increased representation of the most shade tolerant species. However, over hundreds of years, moderate disturbance events can be expected to impact many stands and provide the opportunity to maintain the representation of some mid-tolerant species in some stands and landscapes. Although uncommon in hemlock-hardwood dominated landscapes, catastrophic disturbance can occur and can significantly alter stand composition and structure. These disturbances should be considered natural processes and part of the represented ecosystems.

Based on studies of prehistoric conditions and processes in hemlock forests, it could be assumed that most reserved hemlock dominated ecosystems would perpetuate themselves. However, regional environmental conditions have changed and will continue to change, and it is highly uncertain as to whether or not most current hemlock stands will be able to sustain their dominance. Recent observations indicate a high potential for long-term conversion to hardwoods, ostensibly dominated by sugar maple, in many stands. Although a variety of factors could influence this potential trend, critical issues include precipitation, herbivory, and diseases and insects (especially hemlock wooly adelgid).

Silvicultural regeneration methods for hemlock are uncertain. Sometimes, reasons for failure are not clear. Maintaining some hemlock forests as reserves will provide a benchmark for comparison with managed systems. This could facilitate the identification of limiting factors and causal mechanisms in different environments, and enable the development of more dependable silvicultural methods.

Direct Human Disturbance

In relict forests, no significant (>10% canopy removal) direct human disturbance since Euro-American settlement (early 1800's) is permissible. Evaluation of historic human disturbance is based on clear evidence and best available information. If direct human disturbance is applied to a relict forest, then the forest will no longer meet definitional criteria and will no longer be classified as relict forest. When possible, relict forests will be designated as relict forest – reserved, irrespective of structural characteristics. The primary management goal of relict forest – reserved is the preservation of natural processes. Where relict forests are classified as uncertain management, potential future human impacts are unknown.

For old-growth – reserved and old forest - reserved, the primary management goal is the long-term development and maintenance of old-growth compositional, structural, and functional attributes within a minimally manipulated environment. Historic human disturbance is irrelevant if the other designation criteria are met. However, once designated, management activities are severely limited.

Allowable Management Activities in Reserved Forests (relict, old-growth, old forests)

Actual implementation of any of the following activities will depend on the planning and decision making process. Once designated as reserved forest, direct human disturbance is limited to:

a. Fire presuppression and suppression
   - Protection of lands adjoining the reserve.
   - Protection of the reserve – activities that protect the reserve from human caused fires and from externally ignited fires are acceptable. Fires that are ignited within the reserve through natural processes (*i.e.* lightning strikes) could be allowed to burn if there is no threat to human life or property.

b. Control of native insects and diseases
Native insects and diseases are functional parts of natural processes. However, human modification of ecosystems can result in aberrant behavior. Unacceptable thresholds, relative to populations and impacts, could be defined.
  - Protection of lands adjoining the reserve.
  - Protection of the reserve – activities that attempt to protect the reserve from aberrant damage are acceptable.

c. Exotic organisms may be controlled and eliminated to the greatest extent feasible, while causing the minimum damage possible to the system being protected. Hemlock woody adelgid is a significant threat to the future persistence of eastern hemlock forests.
d. Herbivore populations may be limited to reduce negative ecological impacts. Browsing by deer can be a critical limiting factor in the development of hemlock regeneration. Herbivore populations and impacts should be monitored.
e. Research and monitoring activities may be facilitated. Monitoring can be utilized to document ecosystem responses to environmental change. Research should not significantly alter forest composition, structure, or function. Destructive sampling should be kept to a minimum.
f. Recreation management should be implemented. Impacts on forest composition, structure, and function should be controlled and limited. Limited foot trail systems are acceptable. Dispersed primitive camping could be acceptable in large reserves. Recreation could be encouraged for educational purposes. Hunting could be used to control animal populations. Motorized recreation should be limited.
g. Infrastructure within reserves should be kept to a minimum. In most cases, structures should be discouraged; when necessary, they should be primitive. In most cases, roads should be discouraged; when necessary, they should be narrow dirt or gravel tracks.

Specific Prohibited Management Activities

a. Timber harvesting and salvage are not permitted.
b. Vegetation management to manipulate compositional, structural, or functional development or to simulate disturbance processes is not permitted (beyond acceptable practices previously identified).

Current Occurrence in the Lake States and Wisconsin

Relict forest – Reserved

Frelich (1995, 2002) estimated that currently there are about 72,000 acres of relict hemlock and northern hardwood forests in the Lake States. Most of this area is reserved. Three distinct landscapes contain most of these relict forests: the Porcupine Mountains (mostly state owned), the Sylvania Wilderness Area (federally owned), and the Huron Mountains (mostly privately owned), all in the Upper Peninsula of Michigan. The Porcupine Mountains and Sylvania Wilderness Area are considered large enough to be functional quasi-equilibrium hemlock-hardwood landscapes. The estimated current hemlock and northern hardwood relict forest area occupies less than one percent of the area it probably covered in the Lake States at the beginning of Euro-American settlement.

Frelich (1995) also estimated that there are less than 1000 acres of relict hemlock and northern hardwood forests in Wisconsin. Relict hemlock forests in Wisconsin mostly occur as small isolated patches surrounded by younger forests (usually hardwood dominated) or developed land.

Old-growth and old forests – Reserved

In Wisconsin, the hemlock forest type occupied approximately 121,000 acres of forest land statewide (<1% of forest land area), and there were about 26,600 acres of hemlock forest land with a stand age class ≥120 years (from summary data, 1996 statewide Forest Inventory and Analysis). A reliable estimate of acres of reserved hemlock forest is not available.

MANAGEMENT CONSIDERATIONS FOR MANAGED AND EXTENDED ROTATION MANAGEMENT CLASSES

Old-growth and old forests can be designated as managed or extended rotation forests, based on structural characteristics and management goals and commitments. Historic human disturbance is irrelevant, if the other designation criteria are met. However, once designated, management activities are limited. To achieve management goals, these forests will have low to moderate severity disturbances of human origin.

Within Wisconsin, representation of hemlock within its region of historical dominance is sparse. Remaining stands range from young to old, even- to uneven-aged, and managed to unmanaged. Most stands are dominated by trees less than 120 years old. Stands often lack the structural complexity characteristic of old, uneven-aged, unmanaged forests. They tend to have fewer large trees (>20 inches DBH), less basal area in large cavity trees and snags, less well decomposed large downed woody debris, less variability in canopy gap size and distribution, and less spatial heterogeneity.

Innovative silvicultural treatments potentially could hasten the development of some desired old-growth attributes (Lorimer and Frelich 1994, Frelich 1995, Lorimer 1995, Hanson and Lorimer 2007). Adaptive silvicultural practices that hasten the development of and maintain ecological attributes associated with old, unmanaged forests require innovation, variability, and conscientious application.

Relatively old managed and extended rotation forests will provide a range of social and ecological benefits. They offer the potential to manipulate ecological processes targeting the achievement of specific benefits. Ecological complexity is expected to be intermediate between young managed forests and old unmanaged forests. Many of the benefits associated with old unmanaged forests can be provided while still maintaining the ability to manipulate developmental processes and also provide additional social benefits. These adaptive management schemes offer the opportunity to provide a unique suite of ecological and social benefits.

Forest Management and Direct Human Disturbance – Considerations and Recommendations

Clear and detailed management goals and objectives are critical for the implementation of sustainable, science-based management of old-growth and old forests designated as managed and extended rotation. Goals and objectives will guide the development of silvicultural prescriptions and the application of vegetation management techniques. Management decisions and silvicultural practices will largely determine the development of ecological conditions. The ecological characteristics described for old, multi-aged, unmanaged forests should be promoted to the greatest extent possible consistent with the management goals and objectives. Site potentials and landscape factors should be included in the analysis of management options.

Managed and extended rotation forests will have, or will develop, an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. Uneven-aged silvicultural systems are tentative, but can be applied and refined through adaptive management. The application of specific silvicultural treatments depends on management goals and objectives, stand condition, and site capability.

Silvicultural treatments that could be adaptively applied include:

- Site preparation offers the opportunity to manipulate species composition.
- Release offers the opportunity to manipulate species composition and foliar height diversity, and to accelerate the growth of desired individuals.
- Thinning and improvement cutting offer the opportunity to manipulate species composition; size distribution; growth rates; foliar height diversity; size, number, and distribution of canopy gaps; and the development of coarse woody debris. Periodic thinning can maintain individual tree diameter and stand basal area growth rates at levels higher than normally expected in old, unmanaged stands . However, thinning of mature stands must proceed incrementally, because excessive crown release can result in stress induced mortality of residual hemlock following logging. As a general guide, maintain crown closure at approximately 90% and release crowns only on 1-2 sides.
- Shelterwood seed cuts offer the opportunity to encourage a pulse of hemlock regeneration and establish a new age cohort. When applied to even-aged stands, shelterwood seed cuts could facilitate conversion to uneven-aged conditions.
- The single-tree selection system offers the opportunity to manipulate stand structure, composition, and regeneration.
- Planting offers the opportunity to manipulate species composition (*e.g.* hemlock in small gaps, and yellow birch and white pine in larger gaps).

- Protection measures (e.g. to limit herbivory) could enable the recruitment of hemlock seedlings into larger size classes.
- Sanitation practices can enable the management of potential forest health problems.
- Salvage enables the realization of economic returns.

Desired structural characteristics of managed (old-growth and old forests) and extended rotation (old forest) forests include:
- Uneven-aged.
- Horizontal and vertical diversity. Diversity can be encouraged by the adaptation and heterogeneous application of uneven-aged techniques (e.g. variable residual densities and size class distributions). Integrating active and passive management could also contribute to the development of diversity.
- Gaps – size, number, and distribution. Management could attempt to approximate gap sizes and distributions characteristic of old unmanaged forests. In size, most canopy gaps are less than 0.045 acres (50 foot diameter circle), and gaps 0.007-0.016 acres (20-30 foot diameter) tend to be most common. Average gap formation rates are 5-6% per decade (per unit area). Disturbance events that remove 20-30% of the canopy can enable widespread recruitment of a new age cohort; however, such events occurred infrequently in natural systems, averaging once every 100-200 years. Gap distribution is highly variable. Heterogeneity in application is recommended.
- Large trees. The representation of large trees is directly related to increasing stand age, but representation can be influenced by management techniques. Management techniques will encourage the development and maintain the representation of large diameter (>20 inches) trees.
  - Retain at least 6 live trees per acre greater than or equal to 20 inches DBH, including 2 trees per acre greater than or equal to 28 inches DBH
- Large diameter cavity trees, snags, and downed woody debris. These structural attributes are directly related to increasing stand age and tree size, but representation can be influenced by management techniques. In managed old forests and extended rotation forests, representation of these structural attributes generally is intermediate in abundance between old, unmanaged forests and younger, more traditionally managed stands. Management techniques will encourage the development and maintain the representation of large diameter (>20 inches) cavity trees, snags, and downed woody debris.

  Retain at least:
  - 6 snags per acre >12 inches DBH, with 3 snags per acre >20 inches DBH
  - 3 cavity trees per acre, with 1 cavity tree per acre >20 inches DBH

Structural perturbations caused by natural disturbances should be integrated into the management regime.

Management Regimes and Silvicultural Systems

Across northern Wisconsin, the potential long-term viability of hemlock regeneration under any management system, active or passive, is highly uncertain. In many stands, there appears to be a high potential for long-term conversion to hardwoods, particularly maples. Although a variety of factors could influence this potential trend, critical issues include precipitation, herbivory, and insects and diseases.

Silvicultural systems, particularly regeneration methods, for hemlock management are not well developed. Reasons for failure of regeneration are not always clear; establishment of seedlings and recruitment of saplings are both issues. Continued research on hemlock ecology and silviculture, and the development of more precise and dependable management guides are needed. Silvicultural recommendations described herein are adapted from current management guides and recommendations, as well as from studies of hemlock ecology; they are premised on adaptive management. Field application will require further adaptation based on observed stand responses to silvicultural treatments.

Similar basic silvicultural methods are recommended for extended rotation (old forest) and managed old forest/old growth. However, management class designation entails some specific and distinct management goals, commitments, and limitations which will result in some differences in application and resultant stand conditions. Managed old-growth will exhibit additional structural features that will need to be incorporated adaptively, including older and larger trees, increased representation of cavity trees and coarse woody debris, and increased heterogeneity; silvicultural treatments will be less frequent, less intensive and extensive, and more heterogeneous.

Uneven-aged management systems that sustain hemlock dominated communities will be applied to extended rotation – old forests, managed – old forests, and managed – old growth. Uneven-aged management will enable the development and maintenance of mature and structurally diverse forests, that are similar to and provide many benefits associated with old, unmanaged forests. Even-aged management systems will not be utilized; although regeneration methods have been more consistently successful, resulting structural diversity and ecological benefits are limited.

One potential method to convert even-aged stands to uneven-aged structure:

- Apply seed cut following shelterwood regeneration method guidelines.
  Consider site preparation needs. Manage regeneration.
  - — Seed cut to 70-80% crown closure. Discriminate against maples.
  - — Site preparation using partial mechanical scarification or low intensity ground fire.
    - o Preferred hemlock seedbeds: mixed humus and mineral soil, mineral soil, thin litter, moss, partially decomposed nurse logs (especially conifers).
  - — Manage regeneration. Consider:
    - o Available moisture for several years following seed dispersal
    - o Protection from herbivory
    - o Competition control
    - o Composition, stocking, and potential to supplement regeneration
- Wait at least 20 years before further overstory treatments.
- Apply single tree selection.

Another potential method to convert even-aged stands to uneven-aged structure:

- Apply even-aged thinning method to develop 90% crown closure. Discriminate against maples. Gaps should be less than 40 feet in diameter, 20-30 feet is ideal. Where advanced regeneration is present, release in small canopy gaps. Consider needs for site preparation and protection from herbivory.
- Repeat treatment at 10-20 year intervals. Thin 2-4 times.
- Shift to single-tree selection.

Uneven-aged single tree selection is the basic recommended silvicultural system. This system can be adapted to achieve specific goals and objectives, and to improve success under different environmental conditions.

- Two available uneven-aged stocking guides are based on a maximum diameter class of either 18 inches or 30 inches, and a residual basal area of 130 square feet per acre; to manage for old forest attributes, adaptively apply the 30 inch stocking guide. Extended rotation will include trees greater than 200 years old and greater than 20 inches DBH; managed old-growth will include increased representation of older and larger trees; reserve trees will attain maximum diameters. Target residual basal area should reflect 90% canopy cover.
- In the absence of stocking guides, reduce canopy closure to 90% every 15-20 years. Residual basal area will generally be in the range of 120-150 square feet per acre. Attempt to retain proportional representation in proportional sawtimber size classes, and somewhat lesser stocking in poletimber.
- Favor high quality trees in each size class (risk, crown vigor, stem quality).
  Discriminate against maples.
- Release crowns of canopy trees on only 1-2 sides, and maintain crown closure at approximately 90%. Excessive crown release can result in stress induced mortality of residual hemlock following logging.
- When cutting trees, reducing canopy cover, and reducing basal area, canopy gaps will be created. Most canopy gaps should be less than 0.02 acres (33 feet in diameter) in size. Release, and periodically re-release, established regeneration and suppressed trees in small canopy gaps.
- Retain unthinned groups and patches to develop and maintain large trees, cavity trees, snags, and downed woody debris.
- Consider seedbed conditions and potential site preparation needs.
- Control competition and herbivory if necessary.
- Apply silvicultural treatments in a heterogeneous manner to encourage development of horizontal patchiness. Include untreated patches and occasional larger gaps.

A shelterwood type seed cut, reducing crown closure to 70-80%, possibly with site preparation, could be implemented every 150-200 years to simulate a more severe disturbance and establish a pulse of regeneration.

Managed – Old-growth (and old forest)

The primary management goal is the long-term development and maintenance of some old-growth ecological attributes within environments where limited management practices and product extraction are allowed. Management of old hemlock forests will develop and perpetuate old-growth age and structural characteristics. These uneven-aged forests will contain some old and large trees. Silvicultural manipulations are primarily intended to influence forest development to achieve specific management objectives. Timber harvests can be a tool to accomplish primary objectives.

Typical reasons to manipulate forest development include:

- Direct or accelerate development of old-growth structural attributes
- Influence species composition
- Simulate natural disturbance
- Forest protection
- Partial salvage
- Research
- Recreation management

Recommended basic single-tree selection guidelines will be further adapted to accomplish managed old-growth ecological goals and objectives.

- Tree cutting may occur less frequently
- Stocking guide may need to be further modified to develop or retain at least 20% of basal area in trees at least 210 years old (greater stocking in larger size classes)
- May retain increased number of old trees, including large old cavity trees
- May increase retention of or create large snags
- Some cut trees will be retained on site as downed woody debris. These generally will be large diameter, low value decaying logs.
- May retain increased representation of uncut groups and patches.
- Treatments may be applied in a more heterogeneous fashion to increase variability through spatial patchiness. Attributes that could be spatially varied include: patches with no treatment for one or more entries, residual canopy cover (e.g. 70-100%) and basal area, distribution of stocking among size classes, canopy gap size and distribution, number of reserve trees and large cavity trees, number of snags, and amount of coarse woody debris.

Compared to traditional management of mature forests or extended rotation management of old forests, less timber will be harvested, because more trees will be retained for old age, large size, and the development of cavity trees, snags, and downed woody debris.

<u>Extended Rotation – old forest</u>

The primary management goals include timber production and the development and maintenance of some ecological and social benefits associated with older forests. Adaptive uneven-aged management techniques will be applied to maintain old forest compositional and structural characteristics. Maintenance of hemlock dominance will be a priority. Structural characteristics expected to be intermediate between old, unmanaged forests and more intensively managed younger forests include:

- Tree age and size – these regulated uneven-aged forests will contain some relatively old and large trees, but most trees will be harvested before the onset of biological deterioration.
- The size and quantity of large cavity trees and coarse woody debris.
- Spatial heterogeneity will be considered and encouraged, but regulation tends to homogenize.

These uneven-aged stands are maintained in perpetuity, but some trees are harvested while young, some at economic maturity, some are grown to approach biological maturity and then could be harvested, while some are retained to live out their natural lifespans; therefore, the rotation is extended for a subset of the trees within an uneven-aged stand.

Extended rotation management of hemlock stands will apply adaptive uneven-aged silvicultural systems as outlined above. The six largest trees per acre should be retained to live out their natural life-spans, and will contribute to stocking in the largest size class. As they develop, they can provide large trees, cavity trees, snags, and downed woody debris. Spatial distribution of permanent retention trees can be variable.

Allowable Management Activities in Managed and Extended Rotation Forests (old-growth and old forests)

Actual implementation of any of the following activities will depend on the planning and decision making process. Once designated, direct human disturbance is limited to:

a. Salvage operations are permitted, but are subject to limits.
   - Managed – partial salvage is permitted. Up to 50% of salvageable materials, by species and size class, may be salvaged. In special cases, where significant negative impacts to forest health, forest fire protection, or forest aesthetics can be demonstrated, additional salvage harvesting could be approved.
   - Extended rotation – nearly full salvage is permitted. Some standing and downed coarse woody debris should be retained.

b. Timber harvest operations are permitted, but are subject to limits.
   - Managed – partial timber harvesting as a tool for vegetation manipulation is permitted. Some examples of potentially valid reasons to cut trees include: maintain vigor of selected trees; enhance composition, structure, or function; manipulate reproduction; simulate natural processes; or accomplish other management objectives (*e.g.* create a vista or firebreak). When merchantable trees are cut, up to 75% of the cut volume, by species and size class, may be harvested. Generally, economically low-value cut trees will be left as coarse woody debris. In special cases, where significant negative impacts to forest health, forest fire protection, or forest aesthetics can be demonstrated, additional harvesting could be approved.
   - Extended rotation – sustainable uneven-aged silvicultural systems to maintain vigorous growth, manipulate composition and structure, and produce quality timber will be applied. As specified above, these silvicultural systems will be adapted to develop and maintain large old trees, large standing and downed coarse woody debris, and structural diversity.

c. Vegetation management to manipulate compositional, structural, and functional development; maintain the vigor of selected trees; and manipulate reproduction is permitted.
   - Managed – light thinning to manipulate composition, accelerate structural development, and maintain vigor of selected trees; light to moderate severity thinning to establish or release reproduction; limited planting; and site preparation are permitted.
   - Extended rotation – silvicultural practices to accomplish management goals and objectives are standard.

d. Simulation of natural disturbance processes is permitted.
   - Managed – occasional light thinning to simulate low intensity natural disturbance is permitted.
   - Extended rotation – silvicultural practices to accomplish management goals and objectives are standard. Management practices that simulate light severity natural disturbance are encouraged.

e. Fire presuppression and suppression – all necessary activities are acceptable.

f. Control of native insects and diseases – all necessary activities are acceptable.

g. Exotic organisms may be controlled and eliminated to the greatest extent feasible, while causing the minimum damage possible to the system being protected. Hemlock woody adelgid is a significant threat to the future persistence of eastern hemlock forests.

h. Herbivore populations may be limited to reduce negative ecological and silvicultural impacts. Control of herbivores may be critical to successful natural regeneration.

i. Research activities may be facilitated to the extent desired.

j. Recreation management should be implemented. Impacts on forest composition, structure, and function should be controlled and limited. Acceptable recreational activities should be specified in the planning process and based on the achievement of management goals.

k. Infrastructure and roads should be planned and limited.

Current Occurrence in the Lake States and Wisconsin

In Wisconsin, the hemlock forest type occupied approximately 121,000 acres of forest land statewide (<1% of forest land area), and there were about 26,600 acres of hemlock forest land with a stand age class ≥120 years (from summary data, 1996 statewide Forest Inventory and Analysis).

Managed – Old-growth and old forests
The managed designation represents an innovative adaptive management paradigm. Currently, few forest stands in Wisconsin represent this combination of ecological and management requisites.

Extended rotation – Old forest
Although uncommon, some hemlock old forests are uneven-aged and being managed as extended rotation forest.

LANDSCAPE CONSIDERATIONS

Current Conditions and Landscape Concerns

Disturbance Regimes

Disturbance regimes, interacting with site and vegetation, direct landscape composition (Frelich 2002). Historical hemlock-hardwood landscapes were characterized by low to moderate severity disturbances that created patches of different ages and resulted in complex multi-aged forests. Landscape composition was relatively stable, dominated by late-successional species with inclusions of early and mid-successional patches. Severe disturbances that initiated succession were rare.

Currently, anthropogenic disturbances are predominant in hemlock-hardwood stands and landscapes. Disturbance is relatively frequent and highly variable in severity; light, moderate, and catastrophic disturbances are all common. The type, severity, and timing of disturbances, and resultant landscape patterns are drastically different than those processes which drove ecosystem dynamics prior to Euro-American settlement. Even-aged early developmental stages and early successional communities are now predominant. Altered disturbance regimes have resulted in altered compositional, structural, and functional attributes within both plant and animal communities.

Grazing of understory plants by deer has become widespread and often intensive, and can alter species composition in stands and across landscapes. The increasing representation of exotic invasive species could alter forest composition and function; hemlock woody adelgid is a significant threat to the future persistence of eastern hemlock forests. Climate change could induce significant changes in ecosystem processes.

Succession and Stand Development

Old, multi-aged hemlock dominated forests, once predominant in northern Wisconsin, have become rare. Hemlock forests are now uncommon, and regeneration is depauperate. Young, even-aged hardwood forests, dominated by sugar maple, red maple, oak, and aspen, have asserted dominance.

Landscape Composition and Structure

Immigration, settlement, and land use by EuroAmericans has resulted in the most severe disturbance to local and regional vegetation during the Holocene (Foster and Zebryk 1993). Logging, land clearance, and agriculture transformed the landscape and altered forest composition, structure, and function. Many areas have reverted to forest, but the effects of large-scale disturbances in the late 1800’s to early 1900’s are pervasive and long-term; ecosystems have changed (Mladenoff and Howell 1980, Foster et al. 1992, Foster and Zebryk 1993, Mladenoff and Stearns 1993, McLachlan et al. 2000).

Altered disturbance regimes driven by anthropogenic activities (*e.g.* deforestation, parcelization, utilization of forest ecosystems) have resulted in fragmented landscapes characterized by relatively small forest patches and abundant edges. Conversion, exploitation, and homogeneous management regimes have resulted in decreased compositional and structural diversity. Significant compositional and structural changes in hemlock-hardwood landscapes include:

- Decreased representation of hemlock
- Decreased representation of yellow birch, white pine, and yew
- Increased dominance of hardwoods, particularly aspen and maples
- Decreased representation of advanced developmental stages (i.e. transition and multi-aged)
- Decreased representation of large old trees with large crowns and rough bark
- Decreased representation of large cavity trees and coarse woody debris
- Decreased within stand horizontal and vertical diversity.
- Significant change in patch shape and size range – few large patches of relatively undisturbed older forests – reduced landscape complexity
- Significant reduction in interior conditions and connectivity
- Decreased representation of species that prefer either large patches of interior forests or structural attributes characteristic of old multi-aged forests (*e.g.* large coarse woody debris), such as some neotropical migratory birds, some forest raptors, woodpeckers, American marten, plethodontid salamanders, some species of beetles and spiders, and some species of fungi and lichens. Species representation, populations, and community composition vary with stand and landscape composition and structure.
- Increased dominance of deer

The maintenance of biological diversity potentially could be facilitated through adaptive forest management that recognizes compositional and structural deficiencies, and which implements techniques to increase representation. Structural diversity provides habitat diversity which helps maintain biodiversity.

Quasi-equilibrium Landscapes

Frelich (1995) stated, "Michigan's Porcupine Wilderness State Park and Sylvania Wilderness Area are the only presettlement-like upland forest landscapes in the Lake States." These contain extensive tracts of relatively undisturbed northern hardwood and hemlock forests, and appear to be quasi-equilibrium landscapes. Michigan's Huron Mountains also contain extensive tracts of relict northern hardwood and hemlock forests, but the current extent is insufficient to meet quasi-equilibrium landscape criteria (Frelich and Lorimer 1991, Frelich 1995, Frelich 2002). Most other hemlock-hardwood landscapes are fragmented and frequently disturbed by human activities.

Frelich (1995) proposes that quasi-equilibrium landscapes dominated by northern hardwood and hemlock forests potentially could be developed on parcels that are at least 13,000 to 20,000 acres or larger. Prior to Euro-American settlement, relatively old and uneven-aged forests dominated hemlock-hardwood landscapes on upland loamy soils. The typical landscape structure was:

- 84-91% uneven-aged hemlock-hardwood,
- 7-12% even-aged hemlock-hardwood,
- 1-4% even-aged aspen-birch, and
- 1-2% birch-maple

(Canham and Loucks 1984, Lorimer 2001, Frelich 2002).

Within these landscapes, windthrow was the predominant disturbance factor.

Conservation Design

The hemlock forest type, once predominant in northern Wisconsin, is now uncommon. It was well adapted to prevailing climatic and site conditions, and predominant disturbance regimes, and was an abundant late-successional community type composed of shade tolerant and long-lived species. However, hemlock forests have not responded well to modern anthropogenic landscapes and disturbance regimes. Landscape structures and disturbance regimes patterned after pre-historical analogues could perhaps foster the maintenance of hemlock communities. Developing and maintaining large patches of mature conifer dominated forests subjected to relatively infrequent light severity disturbance may foster the successful regeneration, recruitment, and maintenance of hemlock across landscapes (Foster and Zebryk 1993, Mladenoff and Stearns 1993). Where forest management goals include the development and perpetuation of structurally diverse hemlock stands and landscapes, management strategies could feature the integration of passive management and extensive, low intensity active management.

Hemlock forests and hemlock-hardwood landscapes could possibly be perpetuated in passively managed reserved forests (i.e. relict, old-growth, old forest) that target the development of old-growth conditions and the maintenance of biological diversity. Reserves can be small or large; ecological benefits are expected to increase with increasing reserve size. Infrequent moderate and catastrophic natural disturbance events that alter forest composition and structure should be expected. A robust system of reserves will consider potential disturbance regimes and facilitate the maintenance of ecosystem representation through replication. Buffers around reserves can be extensively managed as old-growth – managed, old forest – managed, and old forest – extended rotation to provide a variety of ecological and social benefits. Management of older forests also provides the opportunity to maintain corridors that connect similar stands and landscapes. The hemlock-hardwood landscape matrix can be managed to produce social and ecological benefits by applying an array of adaptive management techniques ranging from extensive to intensive (e.g. uneven-aged, infrequently disturbed, and relatively old to even-aged with frequent disturbance and relatively short rotations).

Ecological Regions

A variety of statewide maps can help identify the ecological potential for the management of forested landscapes with significant representation of hemlock. Some potentially useful maps are:

- *Sections and Subsections of Wisconsin* by Wisconsin DNR (2002), Appendix A, Figure A.2. This map depicts the National Hierarchical Framework of Ecological Units (NHFEU) in Wisconsin. Nested levels include two Divisions and Provinces, thirteen Sections, and forty-one Subsections (over two hundred fifty Landtype Associations are nested within the Subsections). Principal delineating criteria are climate, geology and geomorphology, hydrography, soils, vegetation, and historic disturbance regimes.
- *Ecological Landscapes of Wisconsin* by Wisconsin DNR (2001), Appendix A, Figure A.3. This map depicts sixteen ecoregions delineated by combining similar NHFEU Subsections.
- *Original Vegetation Cover of Wisconsin* by R.W. Finley (1976), Appendix A, Figure A.4. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is subjective and includes interpretation of survey notes.
- *Land Cover of Wisconsin Prior to Widespread Euro-American Settlement (1832-1866)* by D.J. Mladenoff and T.A. Sickley (2005 unpublished), Appendix A, Figure A.5. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is quantitative.
- *Wisconsin's Land Cover in the 1800s* by D.J. Mladenoff, Appendix A, Figure A.6. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is quantitative.

National Hierarchical Framework of Ecological Units (NHFEU)

The National Hierarchical Framework of Ecological Units can help analyze spatial distributions and temporal potentials for landscape management applications. Provinces, Sections, and Subsections are landscape units mapped at different geographic scales and characterized by unique associations of biophysical factors (*e.g.* climate, topography, landform, soil, vegetation) which differentiate land areas in terms of ecological capabilities and potentials for management (Appendix A, Fig. A.2).

Much of Province 212 was historically dominated by hemlock-hardwood old-growth forests. Hemlock was common in most Sections (except K, western Q, and western Y in northwest Wisconsin). Sections X and J supported extensive hemlock forests, currently support the most hemlock trees and stands, and are extensively forested. Other Sections with good potentials for hemlock management are T and eastern Q. Portions of eastern Y (Bayfield Peninsula) and Z (near lakeshore) also offer potential for hemlock stand management. Throughout province 222, hemlock stands only occur as rare relicts or outliers.

Forest Habitat Type Classification System (FHTCS)

The forest habitat type classification system can be applied to temporal and spatial aspects of stand and landscape evaluation and management. The habitat type series associated with potential late-successional dominance by hemlock are: sugar maple-hemlock and sugar maple-hemlock-beech. In northern Wisconsin, hemlock forests most commonly develop on wet-mesic and mesic sites that are nutrient medium to rich. Hemlock is most common and apparently most competitive on the moister, more nutrient medium portion of this gradient. Ideal habitat types that offer the best potential for the management and perpetuation of hemlock communities are:

- TMC and ATM are very common and offer the best overall potential for hemlock management,
- ATAtOn, ATFSt, ATFD, ATD, and ATDH also offer good opportunities.

Hemlock stands occur and can be managed on richer sites (e.g. AOCa and ACaI), but hardwood competition can be a significant barrier. Hemlock stands can occasionally occur on other site types (e.g. some wet-mesic, nutrient poor-medium sands, and some apparently drier sites subjected to lake effects), but management potentials are limited.

Hemlock generally does not occur on southern habitat types. Only two uncommon southern habitat types typically support hemlock patches:

- AFTD – mesic and nutrient medium-rich – near Lake Michigan and Green Bay
- ATTr – mesic and nutrient medium-rich – relic hemlock stands in the Baraboo Hills

Climate and disturbance regimes characteristic of southern Wisconsin do not support the development of extensive hemlock forests.

REPRESENTATIVE STANDS AND LANDSCAPE FOR ECOLOGICAL CLASSES

A resource to locate representative communities is the WDNR State Natural Areas Program
http://dnr.wi.gov/org/land/er/sna/

Relict Forest

- Porcupine Mountains State Park, MI DNR, Reserved
- Sylvania Recreation Area, Ottawa National Forest, MI, Reserved
- Alvin Creek Headwaters, Forest County, Reserved
- Plum Lake Hemlock Forest, Vilas County, Reserved
- Patterson Hemlocks, Oneida County, Reserved
- Moose Lake Hemlocks, Iron County, Reserved
- Memorial Grove Hemlocks, Price County, Reserved
- Flambeau River Hardwood Forest, Sawyer County, Reserved
- Outer Island Hemlocks, Ashland County, Reserved
- Totagatic Highlands Hemlocks, Washburn County, Reserved
- Jung Hemlock-Beech Forest, Shawano County, Reserved

Old-growth Forest

- Pat Shay Lake Hemlocks, Forest County, Reserved
- Echo Lake Hemlock Hardwoods, Forest County, Reserved
- McClintock Hemlocks HCVF, Marinette County, Managed
- Van Vliet Lake Hemlocks, Vilas County, Managed
- Enterprize Hemlocks, Oneida County, Managed
- Long Lake Hemlocks, Oneida County, Reserved
- Catherine Lake Hemlock-Hardwoods, Iron County, Reserved
- Moose Creek Complex, Iron County, Reserved
- Carpenter Creek Forest HCVF, Iron County, Reserved
- Sieverson Hemlocks, Price County, Reserved
- Swamp Lake Hemlocks, Sawyer County, Managed
- Bear Creek Hemlocks, Taylor County, Reserved
- Perkinstown Moraine Hemlocks, Taylor County, Reserved
- Carlsville Bluff, Door County, Managed

Old Forest

- Alvin Hemlocks, Forest County, Reserved
- Double Bend Hemlocks and Cedar Swamp, Forest County, Managed
- Goodman Wild Lakes, Florence County, Reserved
- McClintock Hemlocks HCVF, Marinette County, Managed
- Hemlock Lake, Oneida County, Managed
- George Ladd Creek Hemlocks, Price County, Managed
- Ashland County Hemlock HCVF, Ashland County, Managed
- Drummond Pines and Hemlocks, Bayfield County, Managed
- Lake Minnesuing Hemlock Hardwoods, Douglas County, Managed

Southern Relicts:

- Hemlock Draw, Sauk County, Reserved
- Mt. Pisgah Hemlock-Hardwoods, Wildcat Mountain State Park, Vernon County, Reserved
- Dells of the Wisconsin River State Natural Area, Adams and Juneau Counties, Reserved

Literature Cited

Alverson, W.S. and D.M. Waller. 1997. Deer populations and the widespread failure of hemlock regeneration in northern forests. In: W.J. McShea, H.B. Underwood, and J.H. Rappole (editors), The science of overabundance: Deer ecology and population management. Smithsonian Press, Washington D.C. pp. 280-297

Anderson, H.W. and A.G. Gordon. 1994. The tolerant conifers: eastern hemlock and red spruce, their ecology and management. Ontario For. Res. Inst, For. Res. Info. Pap. No. 113

Anderson, R.C. and O.L. Loucks. 1979. White-tail deer influence on structure and composition of Tsuga canadensis forests. J. Appl. Ecol. 16:855-861

Bolliger, J., L.A. Schulte, S.N. Burrows, T.A. Sickley, and D.J. Mladenoff. 2004. Assessing ecological restoration potentials of Wisconsin (U.S.A.) using historical landscape reconstructions. Rest. Ecol. 12(1):124-142

Busing, R.T. 2005. Tree mortality, canopy turnover, and woody detritus in old cove forests of the southern Appalachians. Ecol. 86(1):73-84

Canham, C.D. and O.L. Loucks. 1984. Catastrophic windthrow in the presettlement forests of Wisconsin. Ecology 65(3):803-809

Dahir, S.E. and C.G. Lorimer. 1996. Variation in canopy gap formation among developmental stages of northern hardwood stands. Can. J. For. Res. 26:1875-1892

D'Amato, A.W. and D.A. Orwig. 2008. Stand and landscape-level disturbance dynamics in old-growth forests in western Massachusetts. Ecol. Mono. 78(4):507-522

Darlington, H.T. 1930. Vegetation of the Porcupine Mountains. Mich. Acad. Sci., Arts, Lett. 13:9-65

Davis, M.B., S. Sugita, R.R. Calcote, and L.E. Frelich. 1992. Effects of invasion of Tsuga canadensis on a North American forest ecosystem. Pages 34-44 in A. Teller, P. Mathy, and J.N.R. Jeffers, editors. Response of forest ecosystems to environmental changes. Elsevier Applied Science, London, UK

Davis, M.B., S. Sugita, R.R. Calcote, J.B. Ferrari, and L.E. Frelich. 1994. Historical development of alternate communities in a hemlock-hardwood forest in Northern Michigan, U.S.A. In: P.J. Edwards, R.M. May, and N.R. Webb, editors. Large-scale ecology and conservation biology. Blackwell, Oxford, UK. pp 19-38

Davis, M.B., R.R. Calcote, S. Sugita, and H. Takahara. 1998. Patchy invasion and the origin of a hemlock-hardwoods forest mosaic. Ecol. 79(8):2641-2659

Duchesne, L.C., C. Mueller-Rowat, L.M. Clark, and F. Pinto. 1999. Effect of organic matter removal, ashes and shading on Eastern Hemlock, *Tsuga canadensis*, seedling emergence from soil monoliths under greenhouse conditions. Can. Field-Naturalist 113(2):264-268

Eckstein, R.G. 1980. Eastern hemlock (Tsuga canadensis) in north-central Wisconsin. Wisc. Dept. Nat. Res., Res. Rep. 104. 20 pp.

Eckstein, R.G. 1995. Poster: Hemlock on state and county forest lands in Wisconsin. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 179-182

Finley, R.W. 1976. Original vegetation cover of Wisconsin (map). USDA Forest Service, N. Cent. For. Exp. Stn., St. Paul, Minn.

Foster, D.R. 1988. Disturbance history, community organization and vegetation dynamics of the old-growth Pisgah forest, south-western New Hampshire, U.S.A. J. Ecol. 76:105-134

Foster, D.R. and T.M. Zebryk. 1993. Long-term vegetation dynamics and disturbance history of a Tsuga-dominated forest in New England. Ecol. 74:982-998

Foster, D.R., T. Zebryk, P. Schoonmaker, and A. Lezberg. 1992. Post-settlement history of human land-use and vegetation dynamics of a Tsuga canadensis (hemlock) woodlot in central New England. J. Ecol. 80:773-786

Frelich, L.E. 1995. Old forest in the Lake States today and before European settlement. Nat. Areas J. 15:157-167

Frelich, L.E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge, U.K.

Frelich, L.E. and L.J. Graumlich. 1994. Age-class distribution and spatial patterns in an old-growth hemlock-hardwood forest. Can. J. For. Res. 24:1939-1947

Frelich, L.E. and C.G. Lorimer. 1985. Current and predicted long-term effects of deer browsing in hemlock forests in Michigan, USA. Biol. Conserv. 34:99-120

Frelich, L.E. and C.G. Lorimer. 1991. Natural disturbance regimes in hemlock-hardwood forests of the upper Great Lakes region. Ecol. Monogr. 61:145-164.

Frelich, L.E. and C.G. Lorimer. 1991. A simulation of landscape-level stand dynamics in the northern hardwood region. J. Ecol. 79:223-233

Frelich, L.E., R.R. Calcote, M.B. Davis, and J. Pastor. 1993. Patch formation and maintenance in an old-growth hemlock-hardwood forest. Ecol. 74:513-527

Goder, H.A. 1961. Hemlock reproduction and survival on its border in Wisconsin. Wisc. Acad. Sci., Arts, Lett. 50:175-180

Godman, R.M. and K. Lancaster. 1990. Tsuga canadensis (L.) Carr. Eastern hemlock. In: Burns, R.M. and B.H. Honkala, tech. coords., Silvics of North America: 1. Conifers. Agric. Hndbk. 654. USDA Forest Service, Wash. D.C.

Goerlich, D.L. and R.D. Nyland. 2000. Natural regeneration of eastern hemlock: a review. In Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. Edited by K.A. McManus, K.S. Shields, and D.R. Souto. USDA For. Serv. GTR NE-267

Goodburn, J.M. and C.G. Lorimer. 1998. Cavity trees and coarse woody debris in old-growth and managed northern hardwood forests in Wisconsin and Michigan. Can. J. For. Res. 28:427-438

Graham, S.A. 1941a. Climax forests of the upper peninsula of Michigan. Ecology 22(4):355-362

Graham, S.A. 1941b. The question of hemlock establishment. J. For. 39:567-569

Hanson, J.J. and C.G. Lorimer. 2007. Forest structure and light regimes following moderate wind storms: Implications for multi-cohort management. Ecol. Appl. 17(5):1325-1340

Hibbs, D.E. 1982. Gap dynamics in a hemlock-hardwood forest. Can. J. For. Res. 12:522-527

Hix, D.M. and B.V. Barnes. 1984. Effects of clear-cutting on the vegetation and soil of an eastern hemlock dominated ecosystem, western upper Michigan. Can. J. For. Res. 14:914-923

Hough, A.B. 1965. A twenty-year record of understory vegetational change in a virgin Pennsylvania forest. Ecol. 46(3):370-373

Howe, R.W. and M. Mossman 1995. The significance of hemlock for breeding birds in the western Great Lakes region. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 125-139

Kelty, M.J. 1986. Development patterns in two hemlock-hardwood stands in southern New England. Can. J. For. Res. 16:885-891

Kelty, M.J. 2000. Silviculture and stand dynamics of hemlock-dominated stands in southern New England: Some lessons from early research. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Kenefic, L.S. and R.S. Seymour. 2000. Growth patterns of Tsuga Canadensis in managed uneven-aged northern conifer stands. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Kotar, J. 1995. Relative importance and regeneration success of hemlock on different habitat types. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 91-97

Kotar, J. and T.L. Burger. 1996. A guide to forest communities and habitat types of central and southern Wisconsin. Dept. of For. Ecol. And Mgmt., Univ. of Wisconsin – Madison, Madison, Wisc.

Kotar, J., J.A. Kovach, and G. Brand. 1999. Analysis of the 1996 Wisconsin forest statistics by habitat type. USDA Forest Service, NC Res. Stn. Gen. Tech. Rep. NC-207. St. Paul, Minn. 166 pp.

Kotar, J., J.A. Kovach, and T.L. Burger. 2002. A guide to forest communities and habitat types of northern Wisconsin, second edition. Dept. of For. Ecol. And Mgmt., Univ. of Wisconsin – Madison, Madison, Wisc.

Lanasa, M., R. Brittain, M. Hyslop, A. Saberniak, and N. Viau. 1995. Poster: Hemlock ecology and management on the Hiawatha National Forester. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 155-156

Lancaster, K.F. 1985. Managing eastern hemlock: a preliminary guide. USDA For. Serv., NEA, NA-FR-30. 5 pp.

Lemarie, D.P., J.A. Young, C.D. Snyder, R.M. Ross, D.R. Smith, and R.M. Bennett. 2000. Relationships of eastern hemlock (Tsuga Canadensis) to the ecology of small streams in Delaware Water Gap National Recreation Area. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Lorimer, C.G. 1995. Dynamics and structural characteristics of eastern hemlock stands. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 43-59

Lorimer, C.G. and L.E. Frelich. 1994. Natural disturbance regimes in old-growth northern hardwoods: Implications for restoration efforts. J. For. 92(1):33-38

Lorimer, C.G., S.E. Dahir, and E.V. Nordheim. 2001. Tree mortality rates and longevity in mature and old-growth hemlock-hardwood forests. J. Ecol. 89:960-971

Loucks, O.L. and J. Nighswander. 2000. Recognizing all-aged hemlock forests. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

McLachlan, J.S., D.R. Foster, and F. Menalled. 2000. Anthropogenic ties to late-successional structure and composition in four New England hemlock stands. Ecol. 81(3):717-733

Miles, M.C. and E.C. Smith. 1960. A study of the origin of hemlock forests in southwestern Nova Scotia. For. Chron. 36:375-392

Mladenoff, D.J. 1995. The role of eastern hemlock across scales in the northern Lake States. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 29-42

Mladenoff, D.J. 2009. Wisconsin’s landcover in the 1800s (map). Wisconsin Department of Natural Resources and The University 0f Wisconsin – Madison. PUB-CE-4017

Mladenoff, D.J. and E.A. Howell. 1980. Vegetation change on the Gogebic Iron Range (Iron County, Wisconsin) from the 1860s to the present. Trans. Wisc. Acad. Sci., Arts, Lett. 68:74-89

Mladenoff, D.J. and F. Stearns. 1993. Eastern hemlock regeneration and deer browsing in the northern Great Lakes region: a re-examination and model simulation. Conserv. Biol. 7:889-900

Orwig, D.A. and M.D. Abrams. 1999. Impacts of early selective logging on the dendroecology of an old-growth, bottomland hemlock-white pine-northern hardwood forest on the Allegheny Plateau. J. Torr. Bot. Soc. 126(3): 234-244

Parshall, T. 1995. Canopy mortality and stand-scale change in a northern hemlock-hardwood forest. Can. J. For. Res. 25:1466-1478

Peterson, C.J. and S.T.A. Pickett. 1995. Forest reorganization: a case study in an old-growth forest catastrophic blowdown. Ecology 76(3): 763-774

Pubanz, D.M. 1995. Poster: Regeneration and historical growth patterns in large-diameter hemlock on Menominee Tribal Lands. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 175-177

Rogers, R.S. 1978. Forests dominated by hemlock (Tsuga Canadensis): distribution as related to site and postsettlement history. Can. J. Bot. 56:843-854

Rooney, T.P. and W.J. Dress. 1997. Species loss over sixty-six years in the ground-layer vegetation of Heart’s Content, an old-growth forest in Pennsylvania, USA. Nat. Areas J. 17(4):297-305

Rooney, T.P., R.J. McCormick, S.L. Solheim, and D.M. Waller. 2000. Regional variation in recruitment of hemlock seedlings and saplings in the upper Great Lakes, USA. Ecol. Appl. 10(4):1119-1132

Ruffner, C.M. and M.D. Abrams. 2003. Disturbance history and stand dynamics along a topographic gradient in old-growth hemlock-northern hardwood forests of the Allegheny Plateau, USA. Nat. Areas J. 23(2):98-113

Schmidt, T.L. 1998. Wisconsin forest statistics, 1996. USDA Forest Service, NC For. Exp. Stn., Resour. Bull. NC-183. St. Paul, Minn. 150 pp.

Schulte, L.A., D.J. Mladenoff, and E.V. Nordheim. 2002. Quantitative classification of a historic northern Wisconsin (U.S.A.) landscape: mapping forests at regional scales. Can. J. For. Res. 32:1616-1638

Stearns, F. 1949. Ninety-years change in a northern hardwood forest in Wisconsin. Ecology 30(3):350-358.

Stearns, F. 1951. The composition of the sugar maple-hemlock-yellow birch association in northern Wisconsin. Ecol. 32:245-265

Strong, T.F. 1995. Poster: Hemlock regeneration by the shelterwood method: 20-year results. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 187-191

Swift, E. 1948. Wisconsin’s deer damage to forest reproduction survey – final report. WI Cons. Dept., Publ. No. 347, Madison, WI

Tubbs, C.H. 1977. Manager’s handbook for northern hardwoods in the north central States. USDA For. Serv., NCFES, GTR NC-39. 29 pp.

Tubbs, C.H. 1995. Aspects of eastern hemlock silvics important in silviculture: an overview. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 5-9

Tyrrell, L.E. and T.R. Crow. 1993. Analysis of structural characteristics of old-growth hemlock-hardwood forests along a temporal gradient. *In*: Fralish, J.S.; McIntosh, R.P.; Loucks, O.L., eds. John T. Curtis, fifty years of Wisconsin plant ecology, Wisconsin Academy of Sciences, Arts & Letters, Madison. pp. 237-246

Tyrrell, L.E. and T.R. Crow. 1994a. Structural characteristics of old-growth hemlock-hardwood forests in relation to age. Ecol. 75:370-386

Tyrrell, L.E. and T.R. Crow. 1994b. Dynamics of dead wood in old-growth hemlock-hardwood forests of northern Wisconsin and northern Michigan. Can. J. For. Res. 24:1672-1683

Tyrrell, L.E., G.J. Nowacki, T.R. Crow, D.S. Buckley, E.A. Nauertz, J.N. Niese, J.L. Rollinger, and J.C. Zasada. 1998. Information About Old Growth for Selected Forest Type Groups in the Eastern United States. USDA, Forest Service, Gen. Tech. Rep. NC-197. 507 pp.

Vasiliauskas, S.A. and L.W. Aarssen. 2000. Interpretation of age-structure gaps in hemlock (Tsuga Canadensis) populations of Algonquin Provincial Park, Ontario, Canada. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Ward, J.S. and D.M. Smith. 2000. Dynamics of Connecticut hemlock stands. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Webster, C.R. and C.G. Lorimer. 2002. Single-tree versus group selection in hemlock-hardwood forests: are smaller openings less productive? Can. J. For. Res. 32:591-604

Webster, C.R. and C.G. Lorimer. 2004. Manipulating group-selection opening size to promote tree species diversity in hemlock-hardwood forests. Pp 299-309 In: Proceedings: SAF 2003 Natl. Conv.

Webster, C.R. and C.G. Lorimer. 2005. Minimum opening sizes for canopy recruitment of midtolerant tree species: a retrospective approach. Ecol. Appl. 15(4):1245-1262

Whitney, G.G. 1984. Fifty years of change in the arboreal vegetation of Heart's Content, an old-growth hemlock-white pine-northern hardwood stand. Ecol. 65:403-408

Willis, G.L. and M.S. Coffman. 1975. Composition, structure, and dynamics of climax stands of eastern hemlock and sugar maple in the Huron Mountains, Michigan. Mich. Tech. Univ., Dept. For. Tech. Bull. 13. 43 pp.

Wisconsin Department of Natural Resources. 1990 (2010). Silviculture Handbook. State of Wisconsin, Department of Natural Resources, Handbook 2431.5

Wisconsin Department of Natural Resources. 2001. Ecological landscapes of Wisconsin (map). State of Wisconsin, Department of Natural Resources, Madison

Wisconsin Department of Natural Resources. 2002. Sections and Subsections of Wisconsin (map). State of Wisconsin, Department of Natural Resources, Madison

Woods, K.D. 2000a. Dynamics in late-successional hemlock-hardwood forests over three decades. Ecology 81(1):110-126

Woods, K.D. 2000b. Long-term change and spatial pattern in a late-successional hemlock-northern hardwood forest. J. Ecol. 88:267-282

Wydeven, A.P. and R.W. Hay. 1995. Mammals, amphibians and reptiles of hemlock forests in the Lake Superior region. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 115-123

Ziegler, S.S. 2000. A comparison of structural characteristics between old-growth and postfire second-growth hemlock-hardwood forests in Adirondack Park, New York, U.S.A. Global Ecol. Biogeogr. 9:373-389

Ziegler, S.S. 2002. Disturbance regimes of hemlock-dominated old-growth forests in northern New York, U.S.A. Can. J. For. Res. 32:2106-2115

Additional References – Hemlock

Barden, L.S. 1979. Tree replacement in small canopy gaps of a Tsuga Canadensis forest in the southern Appalachians, Tennessee. Oecologia 44:141-142

Bockheim, J.G. 1997. Soils in a hemlock-hardwood ecosystem mosaic in the Southern Lake Superior Uplands. Can. J. For. Res. 27:1147-1153

Bockheim, J.G. and S.E. Crowley. 2002. Ion cycling in hemlock-northern hardwood forests of the Southern Lake Superior Region: a preliminary study. J. Environ. Qual. 31:1623-1629

Borgmann, K.L., D.M. Waller, and T.P. Rooney. 1999. Does balsam fir (Abies balsamea) facilitate the recruitment of eastern hemlock (Tsuga canadensis)? A. Midl. Nat. 141:391-397

Braun, E.L. 1950. Deciduous forests of eastern North America. Free Press, New York. 596 pp.

Brugam, R.B., M. Giorgi, C. Sesvold, S.M. Johnson, and R. Almos. 1997. Holocene vegetation history in the Sylvania Wilderness Area of the western Upper Peninsula of Michigan. Am. Midl. Nat. 137:62-71

Campbell, J.L. and S.T. Gower. 2000. Detritus production and Soil N transformations in old-growth eastern hemlock and sugar maple stands. Ecosystems 3:185-192

Collins, S.L. 1990. Habitat relationships and survivorship of tree seedlings in hemlock-hardwood forest. Can. J. Bot. 68:790-797

Crow, T.R. 1995. The social, economic, and ecological significance of hemlock in the Lake States. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 11-17

Davis, G. and A.C. Hart. 1961. Effect of seedbed preparation on natural reproduction of spruce and hemlock under dense shade. USDA For. Serv., NEFES, Stn. Pap. No. 160. 12 pp.

Davis, M.B. 1981. Quarternary history and the stability of forest communities. In Forest Succession, ed. D.C. West, H.H. Shugart, and D.B. Botkin, 132-153. New York, Springer-Verlag

Davis, M.B. 1987. Invasions of forest communities during the Holocene: beech and hemlock in the Great Lakes region. In: Colonization, Succession and Stability, Edited by A.J. Gray, M.J. Crawley, and P.J. Edwards, Blackwell, Oxford, UK. pp. 373-393

Davis, M.B., K.D. Woods, S.L. Webb, and R.P. Futyma. 1986. Dispersal versus climate: expansion of Fagus and Tsuga into the Upper Great Lakes region. Vegetatio 67:93-103

Davis, M.B., S. Sugita, R.R. Calcote, T.E. Parshall, and J.B. Ferrari. 1995. 3000 years of abundant hemlock in Upper Michigan. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 19-27

Davis, M.B., T.E. Parshall, and J.B. Ferrari. 1996. Landscape heterogeneity of hemlock-hardwood forest in northern Michigan. Pages 291-304. In: Eastern old-growth forests: prospects for rediscovery and recovery. Edited by M.B. Davis. Island Press

Dunn, C.P., G.R. Guntenspergen, and J.R. Dorney. 1983. Catastrophic wind disturbance in an old-growth hemlock-hardwood forest, Wisconsin. Can. J. Bot. 61:211-217

Fajvan, M.A. and R.S. Seymour. 1993. Canopy stratification, age structure, and development of multicohort stands of eastern white pine, eastern hemlock, and red spruce. Can. J. For. Res. 23:1799-1809

Foster, D.R. 2000. Hemlock's future in the context of its history: an ecological perspective. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Frelich, L.E. and P.B. Reich. 1996. Old growth in the Great Lakes region. In: Eastern old-growth forests: prospects for rediscovery and recovery. Davis, M.B., ed. Island Press, Covelo, CA. 420 pp.

Fuller, J.L. 1998. Ecological impact of the mid-holocene hemlock decline in southern Ontario, Canada. Ecol. 79(7):2337-2351

Kavanagh, K. and M. Kellman. 1986. Performance of Tsuga canadensis at the centre and northern edge of its range: a comparison. J. Biogeog. 13:145-157

Mladenoff, D.J. 1987. Dynamics of nitrogen mineralization and nitrification in hemlock and hardwood treefall gaps. Ecol. 68(5):1171-1180

Rooney, T.P. and D.M. Waller. 1998. Local and regional variation in hemlock seedling establishment in forests of the upper Great Lakes region, USA. For. Ecol. & Mgmt. 111:211-224

Runkle, J.R. 1991. Gap dynamics of old-growth eastern forests: management implications. Nat. Areas J. 11(1):19-25

Runkle, J.R. 2000. Canopy tree turnover in old-growth mesic forests of eastern North America. Ecology 81(2):554-567

Solomon, D.S. and W.B. Leak. 2000. Growth and stocking of eastern hemlock (Tsuga Canadensis) in New England. In: K.A. McManus, K.S. Shields, and D.R. Souto, editors, Proceedings: symposium on sustainable management of hemlock ecosystems in eastern North America. USDA For. Serv. GTR NE-267

Stearns, F. 1986. Ecological view of the second hardwood forest and implications for the future. In: Proceedings, the Northern Hardwood Resource: Management and Potential. Edited by G.D. Mroz and D.D. Reed. Mich. Tech. Univ., Houghton, Mich. pp. 51-66

Waller, D.M., W.S. Alverson, and S. Solheim. 1995. Local and regional factors influencing the regeneration of eastern hemlock.. In: Proceedings, Hemlock ecology and management, edited by G. Mroz and J. Martin, Dept. of For, Univ. Wisc. – Madison. pp. 73-90

Whitney, G.G. 1987. An ecological history of the Great Lakes forest of Michigan. J. Ecol. 75:667-684

Whitney, G.G. 1990. The history and status of the hemlock-hardwood forests of the Allegheny Plateau. J. Ecol. 78:443-458

CHAPTER 18

BOTTOMLAND HARDWOOD

DESIGNATION OF ECOLOGICAL AND MANAGEMENT CLASS

Ecological Class

To meet minimum requirements for initial designation as relict forest, old-growth forest, or old forest, bottomland hardwood stands must meet one of the following criteria:

D. Relict Forest
    2. Past and current stands on the site apparently have not been exploited, manipulated, or severely disturbed (>10% canopy removal) by humans since about 1800 AD, based on best available information. Stands lying near the open water of impoundments caused by dams is not acceptable.
        c. Relict Old-growth Forest: both relict and old-growth, meeting conditions detailed in both "A" and "B".

E. Old-growth Forest
    4. Mixed species composition or stands predominantly silver maple - At least 20% of stand basal area comprised of trees at least 130 years old, and 1 tree per acre greater than 30 inches DBH.
    5. Swamp White Oak – At least 20% of stand basal area comprised of trees at least 170 years old and one tree per acre greater than 30 inches DBH.

F. Old Forest
    3. Mixed species composition or stands predominantly silver maple - At least 20% of stand basal area comprised of trees at least 110 years old, and 12 square feet per acre in trees 24 inches DBH and greater.
    4. Swamp White Oak - At least 20% of stand basal area comprised of trees at least 120 years old and one tree per acre greater than 24 inches DBH.

Management Class

Once the ecological class is determined, the management goals and commitments will determine the designation of the appropriate management class: **reserved**, **managed**, **extended rotation**, or **uncertain management**. Each management class is defined by distinctive management goals, commitments, and limitations. Therefore, once designated, the different management regimes are expected to result in the development of distinctive forest conditions.

Exceptions

3. Designated landscapes can include younger stands, if these occupy less than 20% of the total area and the management commitment is adhered to. Note: the 20% rule accommodates the range of natural mortality over a series of flood pulse events.
4. If natural disturbance alters stand or landscape structure to a point below the designation threshold, the previous designation can be maintained if the management commitment is adhered to.

DESCRIPTION OF BOTTOMLAND HARDWOOD COVER TYPE

Overstory Composition

Any combination of eastern cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), river birch (*Betula nigra*), swamp white oak (*Quercus bicolor*), silver maple (*Acer saccarinum* , and American elm (*Ulmus americana*) comprises more than 50% of the basal area in stands of forest trees. Hardwood dominated forests can occur on floodplains and some terraces (WDNR, 1990).

Cottonwood is commonly found along streambanks and bottomlands in the southern two-thirds of Wisconsin. An excellent pioneer of recently disturbed sites, cottonwood requires a continuous supply of moisture throughout the growing season. Cottonwood grows best on medium textured soils with good internal drainage; growth is poor on excessively wet sites and areas of impeded drainage. Cottonwood is also very intolerant of shade. In terms of lifespan, it has an average of 75 years and a maximum life span of 200 years.

Green ash is usually confined to bottomland sites. However, it will grow well when planted on moist upland sites. In Wisconsin, it is most commonly found on wet, rich alluvial soils in the southern half of the state. Green ash is usually mid-tolerant of shade and less tolerant than swamp white oak and silver maple.

River birch occurs at the northern edge of its range in southwestern Wisconsin. It extends north along the Wisconsin River to Stevens Point and the St. Croix River to Burnett County. It prefers deep rich alluvial soils that are sometimes flooded for weeks at a time. River birch is generally intolerant of shade.

Swamp white oak commonly occurs on wet sites characterized by hardpan or areas subject to flooding. In Wisconsin, it is most commonly found as a component of bottomland hardwoods. Swamp white oak is mid-tolerant of shade and has a maximum lifespan of 300 to 350 years.

Silver maple is characteristically a bottomland species, common within alluvial flood plains. It occurs on all major soil types, but is more common on medium to fine textured soils. Silver maple is mid-tolerant of shade and has an average life span 130 years.

American elm was an important component of bottomland forests, but Dutch elm disease has killed most large elm trees. Elm seedlings and saplings may be locally abundant, but are not generally favored by foresters due to continuing disease problems. The average life span of elm has been significantly reduced due to Dutch elm disease.

Within the bottomland hardwood cover type, the predominant associates in Wisconsin are: hackberry (*Celtis occidentalis*), black willow (*Salix nigra*), bur oak (*Quercus macrocarpa*), basswood (*Tilia americana*), red maple (*Acer rubrum*), red oak (*Quercus rubra*), and black ash (*Fraxinus nigra*) (2005 FIA data). Many other tree species can be found as occasional associates including sycamore (*Platanus occidentalis*) and honey locust (*Gleditsia tricanthos*) near the Illinois border, where both reach their northern range limits. The mix changes and species drop out going north with silver maple, green ash and box elder (*Acer negundo*) dominating near Lake Superior.

Predominant shrubs are also flood tolerant. Prickly ash, nannyberry, and wahoo are especially common on levees. Musclewood, several dogwood species, and common elder are commonly found on the flat areas. In addition, these flatter areas have an abundance of lianas (climbing vines), especially poison ivy, ground ivy, greenbriars, and grapes. Along the river course or around backwater and oxbow areas the common shrubs are buttonbush, silky dogwood, red-osier dogwood, and bladdernut.

The understory of a healthy floodplain forest might include ostrich fern, sensitive fern, green dragon, green-headed coneflower, cardinal flower, Virginia bluebells, false dragonhead, sneezeweed, wood nettle, and an abundance of distinctive graminoid species. Especially important are grasses and sedges. Many stands, some but not all heavily disturbed by humans, now have extensive populations of invasive exotics plant including reed canary grass, exotic buckthorns, moneywort, creeping Charlie, and stinging nettle.

Site Characteristics – Soils and Hydrology

Bottomland hardwood forests are intricate and variable ecosystems due to species richness, flooding, ice movement, and internal drainage patterns. A complex pattern of deposition and soil development is characteristic due to multiple disturbance events. Being associated with waterways that periodically flood, the soils are stratified. Typical soil profiles have horizons of distinctly different texture classes deposited by flowing water. Soil textures are often a mixture of organic material, sands, silts, and clays developing complex microsites.

The mineral soil texture and organic soil content is strongly associated with its microsite position in relation to the river channel. The coarsest sediments are deposited immediately adjacent to the river channel (Tepley *et al*., 2004). Finer soils are deposited in increasing volume away from the river channel. Back channels, pits, depressions, oxbows and sloughs are poorly drained and can accumulate deep organic matter (Bell and Johnson, 1974).

River cross-sections of free-flowing third order and above rivers have identifiable landforms (Baker and Barnes, 1998). Next to the river are natural levees of better drained, coarse textured soils providing conditions for excellent growth of eastern cottonwood and sycamore with river birch occurring on the side slopes. Immediately adjacent to the levee is a flat terrain composed of fine-textured mineral soils providing conditions suitable for silver maple, green ash, hackberry, and American elm. Scattered throughout the flat terrain are areas of old river channels or low backswamp. These areas have finer sediments and usually experience prolonged soil saturation. Silver maple and black ash are most often found in the low areas, old river channels and backswamps. The older levees next to the backswamps and oxbows can also have eastern cottonwood and river birch as the predominate species. Swamp white oak is more common on the slightly higher periphery. Many of the larger rivers have second slightly higher terraces that may contain additional species such as bur oak, basswood, black walnut (*Juglans nigra*), shagbark hickory (*Carya ovata*), and white oak (*Quercus alba*) (Bayley, 1995).

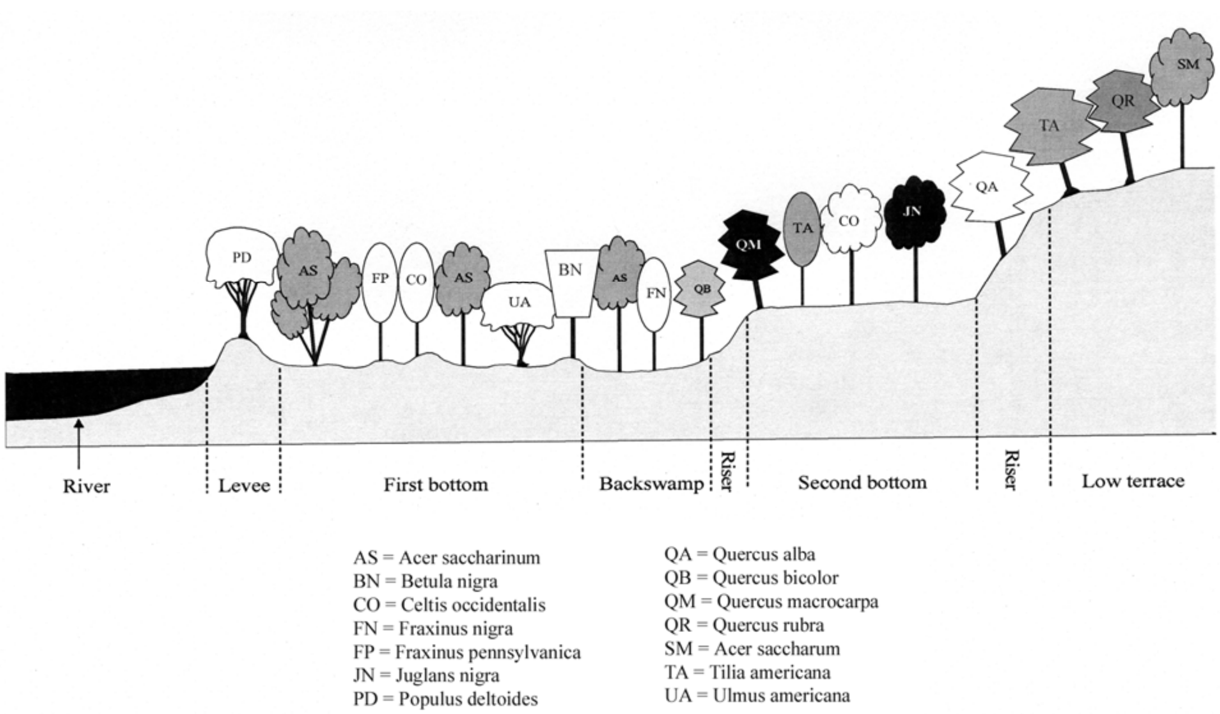


Figure 1. Idealized cross-section of river valley, southern Wisconsin, illustrating the relation of canopy trees to fluvial landforms (Adapted from Michigan Natural Features Inventory).

The occurrence and growth potential of the bottomland hardwood cover type, and of the individual species comprising the type, vary by microsite characteristics and hydrological systems. Current relative occurrence and relative growth potentials for the bottomland hardwood cover type by generalized hydrological type are:

Floodplain sites

- Predominant cover type along major rivers in southern Wisconsin.
- Differences found above and below dams.
- Relative growth potentials range from good to excellent.

Wet soil areas

- Common occurrence in southern Wisconsin.
- Many on former agricultural lands – ditched, drained and subsequently abandoned areas are often times invaded by elm and ash, and especially cottonwood, black and "crack" willow (*Salix fragilis*), balsam poplar (*Populus balsamifera*) west of Green Bay and the lower Wolf River basin. These areas have low potential for old-growth.
- Relative growth potentials range from poor on nutrient-poor sites to moderate on nutrient-rich sites.

Succession and Stand Development

The dynamic process of free-flowing river channel movement creates a diversity of landscape features in floodplains. Processes of over-bank flooding, transport and deposition of sediment, erosive and abrasive water movement, ice-scouring, wind and fire shape the floodplain with multi-varied vegetation patterns (Baker and Barnes, 1998; Turner *et al*., 2004). Even though disturbance patterns are varied, some fluvial landforms are more closely aligned with certain tree species (Hoagland, *et al*., 1996).

Floodplain forest found in impounded areas lack the flood pulse dynamic, have nearly continuous high soil moisture and tend to be much less diverse vegetation (Upper Miss River NW&FR). The species composition is most closely associated with the backswamp community of the free-flowing system. Silver maple, sometimes found in nearly pure stands, is the most common dominant.

The late-successional, potentially climax species-concept is less practical to apply in a floodplain situation (Middleton, 2002). The concept of disturbance-induced seed establishment processes and subsequent flood-tolerance are instructive concepts. All predominately bottomland hardwood species are either intolerant or moderately tolerant to shading. More confounding to the understanding of canopy succession is that the most shade tolerant species, silver maple, is much shorter lived than mid-tolerant species such as green ash and swamp white oak. Frequent disturbance, ecologically unstable systems (long-term), high microsite variability, and the lack of long-lived shade tolerant species adapted to the predominant environmental conditions result in complex vegetation dynamics that rarely reflect traditional successional concepts.

Common Silvicultural Systems and Rotation Ages

Some guidance is given in Chapter 47, Bottomland Hardwood of the Silviculture Handbook (2431.5). In the chapter, general silviculture guidelines will require site-specific refinements. Uneven-aged or even-aged management may apply depending upon species composition, landowner objectives and regeneration strategies. Precautions against harvest should be considered when abundant reed canary grass (*Phalaris arundinacea*), or sedges (*Carex* spp.) are present. Group selection or irregular shelterwood systems are recommended for green ash and swamp white oak. Shelterwood is recommended for stands of green ash and swamp white oak without a significant reed canary grass ground layer. Clearcuts are generally discouraged, although in some cases, stands can regenerated by coppice.

Rotation will vary by species mix, stand origin, site quality and management objectives. Fifty to sixty years is recommended for stump origin, low-quality stands, and for cottonwood. Green ash can be grown to 18 inches DBH and 80 to 100 years on good sites. Silver maple can be grown to 24 inches DBH or more in 80 to 110 years on good sites. Swamp white oak is longer lived with trees reaching 300 years on good sites; traditional rotations would be 80 to 120 years.

Disturbance – Natural and Human

Significant natural disturbances of bottomland hardwood ecosystems include flood pulses, weather events, fire, insects and diseases, and herbivory. Floods are the most significant agent of natural disturbance in both historic and current bottomland hardwood forests. Floods result in fresh sand and silt deposition, uprooting of trees, and floating away and logjamming of substantial coarse woody debris within linear landscapes. Canopy disruptions may range from minor and patchy to catastrophic and extensive. Natural disturbance regimes are further detailed in the next section on ecological characteristics.

Bottomland hardwood landscapes are seasonally inundated, tend to be patchily moist but dry in late summer, and are fire prone in certain locations at some seasons. Both historically and currently, fire in portions of the lower Wisconsin, lower Black, and lower Chippewa River floodplains has been frequent. Formerly, the Mississippi River systems and flowage areas on the other major rivers experienced the same phenomenon (Barnes, 1991; Post, 1994; Nelson *et al., 1997*). Seasonal drought on the sand and gravel areas can predispose these stands to frequent fire. Windthrow is an important disturbance with canopy disruptions ranging from minor to severe. Many wind events usually cross the linear habitat, although river valleys sometimes channel wind.

Currently, dense patches of reed canary grass, glossy buckthorn (*Rhamnus frangula*), and deer herbivory can significantly impact species regeneration and future composition. Dense patches of reed canary grass can totally prevent regeneration of trees and light infestation can become dense, if the canopy is opened much beyond 80% cover. Deer herbivory impacts are varied with some large floodplain such as the lower Wisconsin and lower Chippewa having much reduce deer numbers in winter, whereas other floodplain such as the Wolf River seem to concentrate the deer. The impacts of potential climate change are uncertain.

Human disturbance has become the dominant factor determining current forest composition, structure, and landscape pattern. Few examples remain from the original stands present when the European settlers arrived (Nelson and Sparks, 1997). Large rivers, the first transportation routes for early settlers, were usually the first areas to be denuded to get fuel for steam ships. Farmers then continued to exploit the trees for fuel and building materials. Log drives were conducted on virtually all the major rivers during the late 19th century. Effects of these log drives include altering the depth and configuration of channels, altering flow regimes, damage to bank structure and silting of backwaters. Significant human disturbances of bottomland hardwood ecosystems include permanent flooding upstream of dams, amelioration of flood pulse events through water storage, land use conversion, alteration of drainage patterns, fire management, forest management (especially logging), hunting, recreation, and introduction of invasive exotic species. Fire control policies and activities are facilitating the canopy closure of many floodplain savannas. Land use decisions are critical in determining the distribution of forests and their landscape context. Forest management decisions are critical in determining forest composition and structure.

Geographic Distribution

Historic

In the mid-1800's, a time of significant Euro-American settlement in the area, the bottomland hardwood forest type occurred primarily in southern Wisconsin (Province 222) along major rivers and other areas with seasonal flowing water (Figures 18-1) (Finley, 1976; Schulte *et al*. 2002; Bolliger *et al*. 2004). Studies of characteristic vegetation occupying Wisconsin landscapes at this time generally do not clearly separate the bottomland hardwood and swamp hardwood forest types. The BH type was somewhat common in most Sections (K, L, M, R) within Province 222, with small intrusions into Province 212, especially sections K and Z (Appendix A, Fig. A.2). American elm was a species of great prominence throughout much of the floodplains. The introduction of Dutch elm disease dramatically decreased the prominence of this species. American elm lives on with seedling establishment and growth through early seed bearing years before the trees succumb to the disease. On sand and gravel stream deposits, fire-driven bur oak, black oak (*Quercus velutina*) or Hill's oak (*Quercus ellipsoidalis*) savannas often developed.

At the time of Euro-American settlement, about 2% of all forests in Wisconsin were bottomland hardwood (Frelich, 1995). Most of these forests were uneven-aged due to persistent disturbance events.

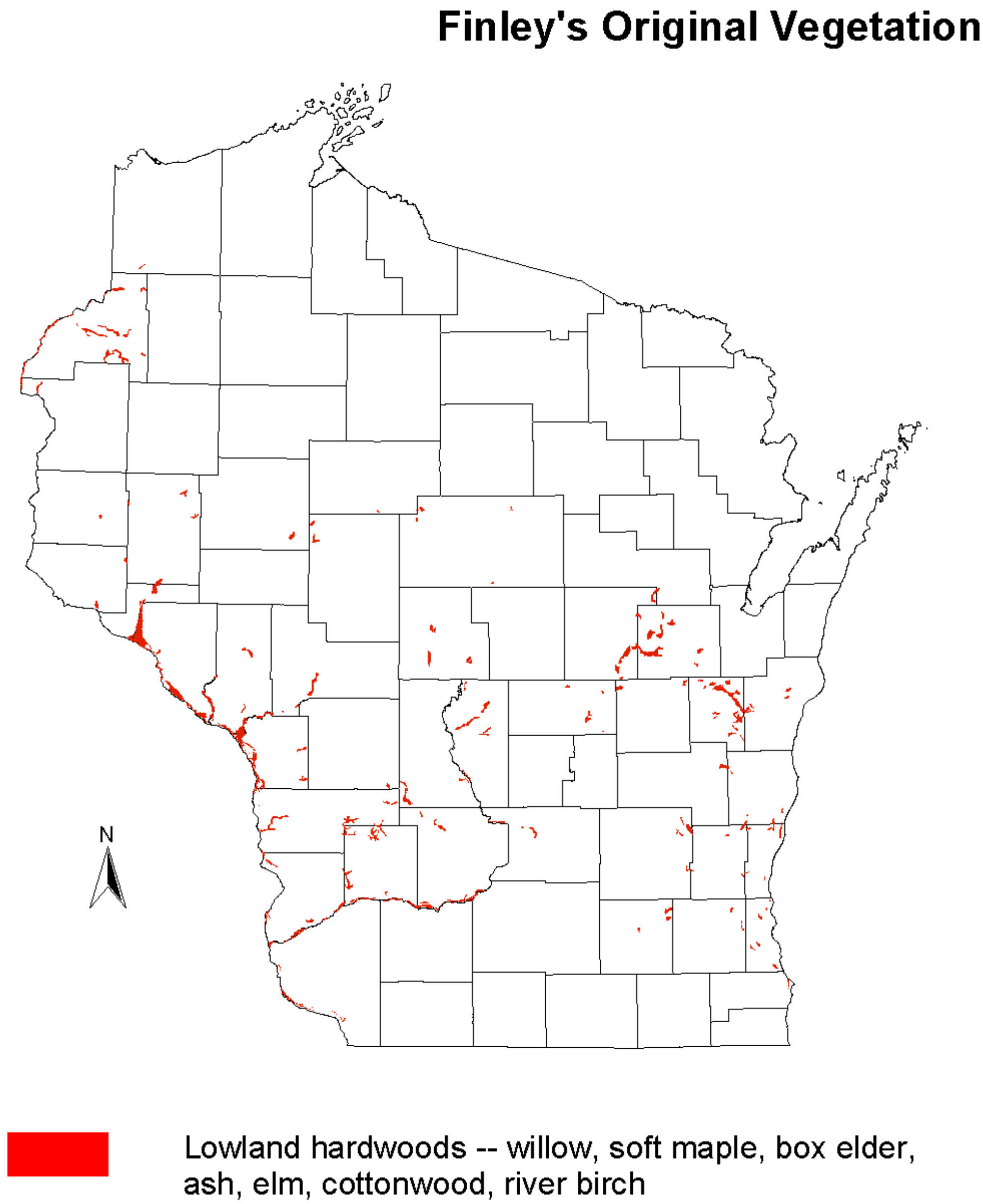


Figure 18-1. Historic statewide distribution of bottomland hardwood forest cover types from *Original Vegetation Cover of Wisconsin* by R.W. Finley (1976).

Current

The bottomland hardwood type is most closely aligned with FIA forest cover types – sugarberry/hackberry/elm/green ash, silver maple/American elm, river birch/sycamore, and cottonwood/willow in Wisconsin. These FIA forest types can provide some information relative to bottomland hardwoods, but the type also documents trees from recovering old fields. Summary data from Wisconsin's sixth statewide forest inventory and analysis (FIA, 2000-2005) elucidates the following data:

f. The sugarberry/hackberry/elm/green ash types covers approximately 322,000 acres, of which 4,200 is older than 100 years. Of course, sugarberry does not occur in Wisconsin.
g. The silver maple/American elm cover type covers approximately 114,000 acres with 7,100 acres being greater than 100 years.
h. The river birch/sycamore type and the cottonwood/willow type are small, approximately 28,000 acres with nothing over 100 years.
i. Swamp white oak was not separated in the cover type analysis

Caution: This data represents the little information available on the age and reserved status of the FIA type. The data is sparse with high levels of statistical error and the bottomland hardwood is only a subset of this data.

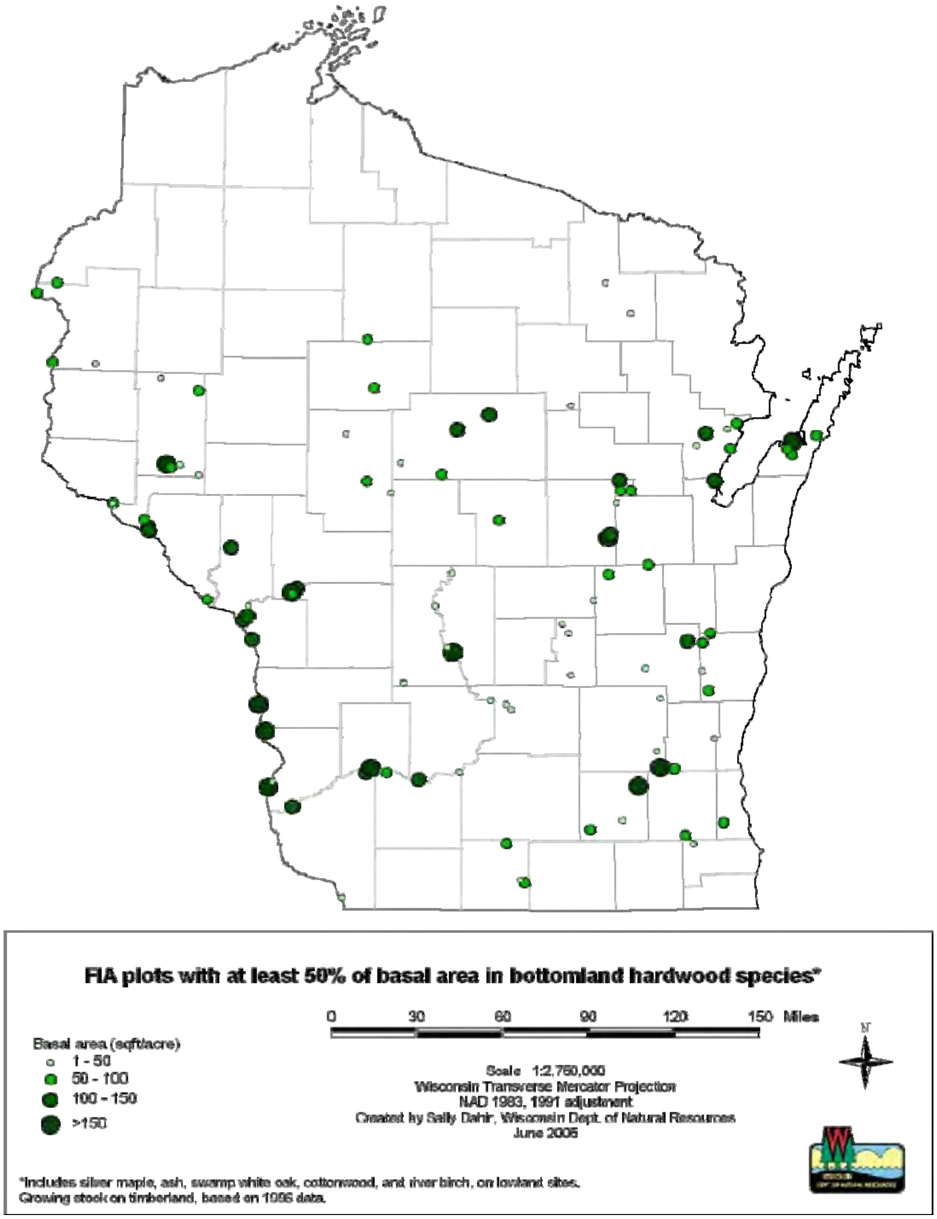


Figure 18-2. Current statewide distribution of bottomland hardwood forest cover type from 1996 Wisconsin Forest Inventory and Analysis (FIA). Map prepared by S. Dahir (2005 unpublished).

ECOLOGICAL CHARACTERISTICS OF RELIT AND OLD GROWTH FORESTS

Old-growth Forest Conditions Begin

Old, multi-aged, unmanaged bottomland hardwood communities rarely develop due to periodic disturbance by flooding, wind and fire. When they do develop, they represent many age and size classes of trees, including numerous old trees and an uneven canopy. Structurally a Rock County stand had most of the stems as seedlings, the canopy had a majority of the trees between 4 and 20" dbh, several 20 to 40" dbh and a few well over 40" dbh (Curtis, 1959). Catastrophic disturbance, primarily in the form of windthrow, occasionally creates large patches. However, the primary regeneration mechanism is flood pulse dynamics. Canopy replacement occurs principally through patch dynamics. Most stands will exhibit non-equilibrium age structure reflecting episodic recruitment of new age classes into the canopy. In a strict sense, under natural conditions, old steady state conditions do not exist in floodplains, because flood tolerance is more important to species succession at a site than shade tolerance (Turner *et al*., 2004). The combination of flooding regime, landscape pattern, land-cover history and soils are particularly important in community composition and abundance of trees (Turner *et al*., 2004). In addition, within broad river valleys fire occurred regularly in savanna communities, but did not kill most of the canopy trees (Post, 1994).

In practice, old-growth conditions begin when overstory trees become relatively old and mortality of large overstory trees becomes significant. A few large canopy gaps are present. Mixed stands contain some representation of old mid-tolerant canopy trees including green ash, silver maple, and swamp white oak; and have a component of species including musclewood (*Carpinus caroliniana*) bitternut hickory (*Carya cordiformis*), hackberry, and basswood that establish only after many decades of relative stability. Groves of silver maple can be nearly pure in composition and need to meet age and structural parameters. Large coarse woody debris distribution is different than in terrestrial systems and is oft times piled in log jams. Typically, these stands will be in the transition stage of stand development. Specific size, age and structural thresholds are identified as designation criteria.

Natural Disturbance Regimes

The primary natural disturbance of bottomland hardwood ecosystems is flooding, typically occurring annually following snowmelt in the watershed, break-up of ice on the major rivers, and occasionally following periods of heavy rain during the growing season. Through movement and deposition of sand, gravel and silt, the soils of the floodplain are overlain both in distance from the river and horizontally over time due to the shifting river course. Floating ice in spring can shear younger trees resulting in many multi-stemmed trees. Water transport of organic material, and especially large woody debris can eliminate organic material in some areas and deposit huge amounts in other areas (e.g. backwater sloughs, log jams). Several months of inundation does not necessarily cause mortality (Army Corps of Eng. Report, 1994; Cosgriff *et al*., 1999)

Other disturbance events are caused by weather events (e.g. wind, snow, ice, hail, flooding, drought), fire, insects and diseases, and herbivory. Although bottomland hardwood forests are generally considered fire resistant, in Wisconsin fires occurred regularly in the broad floodplains of the lower Wisconsin and lower Chippewa Rivers (Post, 1994; Nelson, et.al., 1997) and to a lesser extent along the Mississippi and Black Rivers. These savanna communities are still illustrated today at Caryville Savanna SNA, Ninemile Island SNA, Tiffany Bottoms SNA, and Avoca Prairie SNA. The frequency and severity of natural disturbance events ranged from frequent light severity flood events, to infrequent and catastrophic events caused by severe floods, wind and fire. The interaction of disturbance type, severity, and timing results in a variety of disturbance regimes and potential forest stand and landscape impacts. For example, the potential impacts on future vegetation composition and structure are quite different when floods deposit several inches of sand along the river channel and an inch of silt in a backwater swamp compared to a relatively stable condition of permanent soil saturation on the margins of impounded areas above a dam.

Tree and Stand Age

Old-growth forests are older than typical managed forests. They are, or will be, uneven-aged. In old, unmanaged bottomland hardwood stands, age distributions are highly irregular within and between stands. Typically, within a stand canopy trees will range in age from 75 (eastern cottonwood) to 300 (swamp white oak) years. The average age often is between 80 and 110 years. Trees 130 -150 years old often are common. The oldest trees in a stand can reach 200-300 years, but sometimes may be less than 80 years old (Meadows & Nowacki, 1995). Others suggest the presence of large diameter bitternut hickory, hackberry and basswood can be a guide to determining an old ecosystem (Turner *et al*., 2004).

In old unmanaged bottomland hardwood stands, mortality rates are high for saplings and large trees (Gergel, et.al., 2002). A gap-maker is a relatively large-crowned canopy tree that dies. Following death, the open space previously occupied by the gap-maker is eventually occupied by another tree that competitively captures the vacated growing space. Gaps usually are captured by previously suppressed mid-tolerant species. Sometimes the gap is caused by the scouring action of flood, which exposes mineral soil and has intolerant species seed onto the fresh soil and grow rapidly.

Succession and Stand Structural Development

Compositional change (succession)

On a specific site, changes occur over time. As fresh deposits of sand are laid down, the site becomes forested by eastern cottonwood, black willow, and river birch. These are relatively short-lived species with black willow starting to break up at 45 - 50 years, eastern cottonwood at 80 - 100 years and river birch slightly longer than cottonwood. The deposits increase until a relative flat area of swell and swale appears inland from the riverside levee. These areas have silver maple, green ash, and American elm as the dominant trees. Lower backwater areas and former river channel oxbows fill with silt providing excellent conditions for silver maple, black ash, and swamp white oak.

Due to the constant influence of floods of variable severity, these species usually do not succeed to something else. More important is the concept of flood tolerance. River birch, silver maple, black ash, green ash, eastern cottonwood, swamp white oak, black willow and American elm are very flood tolerant. For example, 80 years after the establishment of a cottonwood, a mid-tolerant silver maple may replace it. However, a flood may topple the cottonwood, at the same time depositing new gravel and potentially reseeding the cottonwood on the same spot. Musclewood, bitternut hickory, hackberry and basswood are considered later succession species in bottomland hardwood communities, but they seldom attain canopy position let alone dominance. Floods prevent saplings from becoming established under many conditions, especially in concert with heavy silver maple shading, thus proving an open park-like understory. (Kotar, 1997; Gergel *et al*., 2002; Turner *et al*. 2004; Tepley *et al*., 2004).

Compositional change has occurred due to the impounding of the major rivers which results in changes to individual sites. Prior to impoundment, the Mississippi River islands were forested with American elm, silver maple, black willow, swamp white oak, river birch, and green ash at about 89 trees/ha. Around Lake Pepin, the floodplain now averages only 12 trees/ha. The floodplains in total had a mixed composition of both the islands and the uplands. A very complex pattern of savannas, prairies, and dense forest developed within an ever-shifting mosaic patterned by flood pulse, late summer drought and fire (Nelson *et al*., 1997).

The impounding of the Mississippi River, the Wisconsin River above Prairie du Sac, the Black River above Black River Falls, and the Chippewa River above Eau Claire created conditions never before experience by floodplain species. While silver maple was co-dominate in several General Land Office (GLO) data sets, the dominance of silver maple increased dramatically after river impoundment (Nelson and Sparks, 1997). Army Corps of Engineers data confirms this with reports of dominant or co-dominant silver maple being in 50% of the stand in 1943, changing to 87% in the 1990s.

Old-growth stands are poorly represented with little quantitative data available. Meadows and Nowacki (1996) suggest cottonwood-willow forest begin to break up around 35 years from establishment and are replaced by eastern riverfront forest (maple-ash-elm). This forest lives for another 80 years before being replaced. However, Meadows and Nowacki indicate that sweet gum (*Liquidambar styraciflua*) and water oak (*Quercus nigra*) are the climax tree species; in Wisconsin, the maple-elm-ash forest is seemingly replaced by itself.

Highly variable microsite conditions determine species distribution across a “stand”. Frequent disturbance, ecologically unstable systems (long-term), high microsite variability, and the lack of long-lived shade tolerant species adapted to the predominant environmental conditions, result in complex vegetation dynamics that rarely reflect traditional successional concepts. Most forests remain in early- to mid-tolerant species composition.

Tree and stand growth rates

Tree growth rates are highly variable. In old-growth bottomland hardwood stands, some trees persist and grow very slowly in shade beneath overstories and on waterlogged sites, while other trees grow rapidly in the middle of large canopy gaps on well-drained, nutrient-rich sites. Growth rates vary by site, stand condition, neighborhood characteristics, species, tree age, and tree size.

Stand structural development and tree size distribution

Data from the University of Wisconsin - Madison Plant Ecology Lab indicates old, unmanaged bottomland hardwoods have many trees in the 10” to 20” size class, many in the 20” to 30” class and several trees over 30” with a few exceeding 40” [elm, silver maple, and swamp white oak] (Curtis, 1959). Coarse woody debris, leaf litter, and other organic material tend to be concentrated due to water transport.

Published information on old-growth bottomland hardwood stand density and canopy stratification is lacking or at least very difficult to find. A similar paucity of information exists for old-growth canopy gap size, gap distribution and community patchiness. Data on the effects of coarse woody debris and cavities is almost exclusively from wildlife management research (Knutson *et al*., 2005)

Understory (shrubs and herbs) composition and spatial structure

In old, unmanaged bottomland hardwood forests, regular flood and wind disturbance events causing single or multiple tree falls resulting in the formation of canopy gaps are important to the maintenance of spatial habitat heterogeneity (Gergel *et al*., 2002). Variations in canopy structure, floodplain topography, and soil deposition regulate available moisture, nutrients, light, and heat, which partially determine understory plant distribution. Spatial heterogeneity enables species segregation and facilitates species maintenance in response to environmental variation (Miller *et al*., 2005). Old-growth forests may provide habitat that could sustain larger populations of some rare species.

Ecosystem Benefits

Some bird species like cavity-nesters are most abundant in old unmanaged bottomland hardwood stands (Mossman, 1988). High bird densities, high species richness, and distinctive assemblages have been associated with floodplains [e.g. prothonotary warbler, yellow-crowned night-heron and red-shouldered hawk] (WDNR, 2005; Hoffman, 2002). Additionally, certain species of insects have been shown to be preferentially associated with American elm (Hoffman, 2002).

Wisconsin species of greatest conservation need include 18 species of bird, 8 species of herptiles, and 9 species of mammals that are significantly or moderately associated with floodplain forest (WDNR, 2005). In addition, many fish species are associated with large rivers and require the interactions of floodplain forest dynamics and water quality functions to provide habitat. Finally, numerous invertebrates, possibly several hundred species of conservation need are found in floodplain systems. Although, these species are found throughout the bottomland hardwood system, ten species that do best in cavities and large tree crowns are assumed to have optimum habitat in old-growth (Mossman, 1988) Bottomland hardwoods slow floodwater, thus lessening the erosive effects of concentrating the flow. Backwater areas hold run-off for extended periods thus providing habitat for many aquatic creatures.

Old-growth forests have larger boles and thus larger standing live tree cavities for animal homes. In old-growth bottomland hardwood forests, some kinds of fungi and lichens demonstrate greater species richness and greater abundance (Hoffman, 2002). Old-growth bottomland hardwoods constitute important habitat for many carnivores, and some endangered species; they are places for ecological research and for recreation and enjoyment. Science has shown that management as well as protection, is necessary and can improve conditions (Tanner and Hamel, 2001).

ECOLOGICAL CHARACTERISTICS OF OLD FORESTS

Based on accepted criteria, old forest conditions begin when trees are older and larger than those managed. These thresholds are identified as designation criteria C (see below). Old forests may experience relatively frequent low to moderate intensity disturbances of either natural or human origin. In bottomland hardwood ecosystems, old forests are presumed to be more common than old-growth because regular disturbance tends to curtail stand development.

Bottomland hardwood stands that fit the old forest designation typically will be in the late stages of normal tree life; basically anything over 110 years. This is a period of structural instability where stands change from a mature even-aged condition to an old, even-aged or a multi-aged one. In natural systems, there is a relatively high potential for episodic disturbance. Forest management can utilize light to moderate intensity disturbance to direct compositional and structural change.

The development of ecological characteristics and benefits will depend on the management class assigned and the management strategy applied (see Management Considerations for Managed and Extended Rotation Management Classes). Barring disturbance, Old Forests – Reserved will develop into old-growth. Old Forests – Managed could develop into old-growth or be maintained as old forest, depending on management objectives and applied silviculture. Those perpetuated as managed forest should exhibit many characteristics and benefits associated with old-growth. The inclusion of human disturbance will result in somewhat more regulated and perhaps more homogeneous conditions, and a somewhat younger and less structurally complex forest. Old Forests – Extended Rotation can maintain a stand an old forest condition, with compositional and structural characteristics intermediate between old-growth and younger managed forests in uneven-aged management systems and until harvest in even-aged systems. Extended rotation forests can provide many characteristics and benefits associated with old-growth, but will be more regulated, more homogeneous, younger, and less structurally complex.

MANAGEMENT CONSIDERATIONS FOR RESERVED MANAGEMENT CLASS

Reserved forests are designated based on disturbance history, structural characteristics, and management goals and commitments. Reserved forest can contain any of the ecological classes: relict forest, old-growth forest, and old forest. Designated stands and landscapes are protected and relatively undisturbed by humans. Therefore, these exhibit - or will potentially exhibit - maximum old-growth characteristics. Typically, they will contain old and large trees for the species and site represented. They have - or will potentially develop - an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. These forests may represent the classic concept of the old-growth bottomland hardwood forest. Reserved bottomland hardwood forests that give us an understanding of the natural functions must be found in floodplains not affected by impounded waters.

In addition, reserved forests may be designated on lands impacted by impounded waters. The lock and dam systems will most likely remain into the distant future. These hydrologically altered landscapes will develop and regenerate differently. We do not know if different old-growth composition and structure will develop.

Bottomland hardwood ecosystems are dominated by relatively flood tolerant species, but flood intolerant species may occur in patches which contributes to the complexity and diversity of bottomland hardwood systems. In reserved forest, successional and developmental processes modified by natural disturbance will determine compositional and structural change, although some indirect human influence and disturbance are unavoidable. In general, longer-lasting and more stable associations are expected to develop with increased representation of the most flood and shade tolerant species. Although uncommon in bottomland hardwood dominated landscapes, catastrophic disturbance can occur and can significantly alter stand composition and structure. These disturbances should be considered natural processes and part of the represented ecosystems.

Direct human disturbance

In relict forests, no significant (>10% canopy removal) direct human disturbance since Euro-American settlement (e.g. the early 1800's) is permissible, including inundation effects of dams. Evaluation of historic human disturbance is based on clear evidence and best available information. If direct human disturbance is applied to a relict forest, then the forest will no longer meet definitional criteria and will no longer be classified as relict forest. When possible, relict forests will be designated as Relict Forest, – Reserved, irrespective of structural characteristics. The primary management goal of Relict Forest – Reserved is the preservation of natural processes. Where relict forests are classified as uncertain management, potential future human impacts are unknown.

For Old-growth – Reserved and Old Forest - Reserved, the primary management goal is the long-term development and maintenance of old-growth compositional, structural, and functional attributes within a minimally manipulated environment. Historic human disturbance is irrelevant if the other designation criteria are met. However, once designated, management activities are severely limited.

Allowable Management Activities in Reserved Forests (Relict, Old-growth, and Old Forests)

Actual implementation of any of the following activities will depend on the planning and decision-making process. Once designated as reserved forest, direct human disturbance is limited to:

a. Fire presuppression and suppression
    - Protection of lands adjoining the reserve.
    - Protection of the reserve; activities that protect the reserve from human caused fires and from externally ignited fires are acceptable. Fires that are ignited within the reserve through natural processes (i.e. lightning strikes) could be allowed to burn if there is no threat to human life or property.

b. Prescribed Fire
    - Oak stands and designated savanna communities could have a plan for use of prescribed fire to maintain the full range of ecological processes.

c. Control of native insects and diseases
Native insects and diseases are functional parts of natural processes. However, human modification of ecosystems can result in aberrant behavior. Unacceptable thresholds, relative to populations and impacts, could be defined.
   - Protection of lands adjoining the reserve.
   - Protection of the reserve; activities that attempt to protect the reserve from aberrant damage are acceptable.

d. Exotic organisms may be controlled and/or eliminated to the greatest extent feasible, while causing the least damage possible to the system being protected.

e. Herbivore populations may be limited to reduce negative ecological impacts. Populations and impacts should be monitored.

f. Deposition of dredge spoils should not occur, although functional restoration of channels and backwater areas may require some level of dredging to reestablish flow patterns.

g. Research and monitoring activities may be facilitated. Monitoring can be utilized to document ecosystem responses to environmental change. Research should not significantly alter forest composition, structure, or function. Destructive sampling should not be conducted or if allowed, kept to a minimum.

h. Recreation management should be implemented. Impacts on forest composition, structure, and function should be controlled and limited. Limited foot trail systems are acceptable. Dispersed primitive camping could be acceptable in large reserves and certain types of recreation could be encouraged for educational purposes. Motorized recreation should be limited. Hunting could be used to control animal populations, if necessary.

i. Infrastructure within reserves should be kept to a minimum. In most cases, structures should be discouraged; when necessary, they should be primitive. In most cases, roads should be discouraged; when necessary, they should be narrow dirt or gravel tracks.

Specific Prohibited Management Activities

a. Timber harvesting and salvage are not permitted.

b. Vegetation management to manipulate compositional, structural, or functional development or to simulate disturbance processes is not permitted beyond acceptable practices previously identified.

Current occurrence in the Lake States and Wisconsin

Relict Forest – Reserved

The current state of knowledge is uncertain. Most floodplains had wood harvested for fuel by riverboat operators and early agriculturists. During times of massive log drives, streamside timber was harvested for fuel, creation of sluice dams, and to remove impediments to the flotilla of logs. Even with these numerous ventures, some areas remained inaccessible. Greater than 200 year old swamp white oaks are known from Tiffany Bottoms, Avon Bottoms, Whitman Bottoms, and Richwood Bottoms SNAs.

Old-growth and Old Forests – Reserved

The 2005 FIA data indicates 11,300 acres of hackberry/elm/green ash and silver maple/American elm are over 100 years old. It is estimated that no acres of river birch/sycamore and cottonwood/willow types are currently greater than 100 years old.

MANAGEMENT CONSIDERATIONS FOR MANAGED AND EXTENDED ROTATION MANAGEMENT CLASSES

Old-growth and Old Forests can be designated as Managed or Extended Rotation Forests, based on structural characteristics and management goals and commitments. Historic human disturbance is irrelevant, if the other designation criteria are met. However, once designated, management activities are limited. To achieve management goals, these forests will have low to high intensity disturbances of human origin.

Traditionally managed bottomland hardwood forests lack some of the structural complexity characteristic of old, unmanaged forests (Nelson and Sparks, 1997). They have fewer large trees (>30 inches DBH) and sometimes fewer tree species. The following management suggestions may increase the structural complexity of traditionally managed forests:

- Increase the range of tree sizes.
- Promote the development of multistoried canopies.
- Increase the abundance and range of sizes for canopy gaps and even-aged patches.
- Retain and increase coarse woody debris.
- Increase the recruitment of tree species other than silver maple.
- Work with dam management agencies to create spring flood pulse events and promote mid to late summer drawdowns.

Traditional silvicultural practices in bottomland hardwoods mostly focuses on timber production, regeneration of species (especially oaks) and providing more diverse wildlife game habitat. The development of old-growth characteristics, innovative silvicultural treatments for managed old-growth and extended rotation are relatively new concepts with little silvicultural research available. Adaptive silvicultural practices that hasten the development of - and maintain ecological attributes associated with old, unmanaged forests - require innovation, variability, and conscientious application. Silvicultural trials may be the best way to start the process of attaining information. Practices that encourage regeneration of silver maple and less economically valuable species such as river birch, hackberry, and cottonwood need to be part these trials.

Relatively old managed and extended rotation forests may provide a range of social and ecological benefits. They offer the potential to manipulate ecological processes targeting the achievement of specific benefits. Ecological complexity is expected to be intermediate between young, managed forests and old, unmanaged forests. Many of the benefits associated with old, unmanaged forests can be provided while still maintaining the ability to manipulate developmental processes and also provide additional social benefits. These adaptive management schemes offer the opportunity to provide a unique suite of ecological and social benefits.

Forest Management and Direct Human Disturbance – Considerations and Recommendations

Clear and detailed management goals and objectives are critical for the implementation of sustainable, science-based management of old-growth and old forests designated as Managed and Extended Rotation. Goals and objectives will guide the development of silvicultural prescriptions and the application of vegetation management techniques. Management decisions and silvicultural practices will largely determine the development of ecological conditions. The ecological characteristics described for Old, Multi-aged, Unmanaged Forests should be promoted to the greatest extent possible consistent with the management goals and objectives. Even-aged management systems can be incorporated into the Extended Rotation mix, but careful analysis of percent of the landscape covered over time needs to be addressed. Site potentials and landscape factors should be included in the analysis of management options.

Managed Old Forests will have - or develop - an uneven-aged structure with many different size classes of canopy trees and some large diameter, standing and downed coarse woody debris. Uneven-aged silvicultural systems can be adapted and applied. Extended Rotation Forests may be managed by either even-aged or uneven-aged systems. The application of specific silvicultural treatments depends on management goals and objectives, species composition, stand condition, and site capability. Silvicultural treatments that could be adaptively applied include:

- Manipulation of species composition and simulation of the effects of natural disturbance via site preparation.
- Release offers the opportunity to manipulate species composition and foliar height diversity, and to accelerate the growth of desired individuals.
- Thinning and improvement cutting offer the opportunity to manipulate species composition; size distribution; growth rates; foliar height diversity; size, number, and distribution of canopy gaps; and the development of coarse woody debris. Periodic thinning can maintain individual tree diameter and stand basal area growth rates at levels higher than normally expected in old unmanaged stands.

- Even-aged regeneration methods within a managed landscape context.
- All-aged – Group gap selection and group patch selection regeneration methods offer the opportunity to manipulate stand structure, composition, and regeneration.
  - In even-aged stands, adaptive conversion techniques should be applied to develop uneven-aged conditions.
  - Adaptively integrating variability in timing and intensity of single-tree selection, group gap and patch selection, and thinning could partially simulate irregular low to moderate intensity disturbances that result in spatial heterogeneity.
- Sanitation practices enable the management of potential forest health problems.
- Salvage enables the realization of economic returns.

Group gap selection tends to favor the regeneration of green ash, swamp white oak and hackberry. Species diversity could be encouraged. Techniques to encourage species diversity include:

- Thinning and improvement cutting to favor desired species.
- Release to favor desired species.
- Site preparation to prepare favorable seedbeds (could include development of nurse logs) and to remove competition.
- Planting oak in patches of 0.5 to 2 acres.

Desired structural characteristics of Managed (Old-growth and Old Forest) and Extended Rotation (Old Forest) forests include:

- Managed Forest will be uneven-aged.
- Extended Rotation Forest may be even-or uneven-aged.
- Horizontal and vertical diversity. Diversity can be encouraged by the adaptation and heterogeneous application of management techniques. Integrating active and passive management could also contribute to the development of diversity.
- Group patches and stands; size, number, and distribution. Management could attempt to approximate patch and stand sizes, and distributions characteristic of old unmanaged forests.
- Large trees. The representation of large trees is directly related to increasing stand age and tree size, but representation can be influenced by management techniques. Management techniques will encourage the development and maintain the representation of large diameter (>30 inches) trees.
- Large diameter cavity trees, snags, and downed woody debris

<u>Managed – Old-growth and Old Forest</u>

The primary management goal is the long-term development and maintenance of some old-growth ecological attributes within environments where limited management practices and product extraction are allowed. Management will perpetuate old forest or old-growth age and structural characteristics. These uneven-aged forests will contain old and large trees for the species and site represented. Silvicultural manipulations are primarily intended to influence forest development to achieve specific management objectives. Timber harvests can be a tool to accomplish primary objectives. Appropriate silvicultural systems are Adaptive Group Selection and Irregular Shelterwood.

Typical reasons to manipulate forest development include:

- Accelerate development of old-growth structural attributes.
- Influence species composition.
- Simulate natural disturbance.
- Forest protection.
- Partial salvage.
- Research.
- Provide and protect habitat for selected species.
- Recreation management.

<u>Extended Rotation – Old Forest</u>

The primary management goals include timber production, and the development and maintenance of some ecological and social benefits associated with older forests. Adaptive management techniques that address the compositional and structural considerations outlined above will be applied. Management activities will encourage old forest age and structural characteristics. These forests will contain some old and large trees for the species and site represented. Most trees will be harvested before the onset of biological deterioration. Some trees are harvested while young, while others are harvested at economic maturity. Some are grown to approach biological maturity and then harvested, while some are reserved to live out their natural life spans. Appropriate silvicultural systems are Group Selection, Irregular Shelterwood, and Shelterwood.

Extended rotation management of bottomland hardwood stands will apply adaptive management techniques to encourage compositional and structural diversity. Extended rotations in even-aged and uneven-aged stands will vary by dominate species.

- Grow some green ash to > 100 years up to 130 years.
- Grow some silver maple to > 110 years up to 130 years.
- Grow some swamp white oak to >120 years up to 200 years.

The management of extended rotations will encourage some compositional and structural attributes characteristic of old, unmanaged forests. However, age and size distribution will be regulated, and there will be fewer trees beyond traditional rotation age or size. The size and quantity of large trees, cavity trees, snags, and downed woody debris will be less developed. Regulated management will result in more regular patches in terms of size, number, and distribution. Species composition will depend on management objectives, site capability, stand condition, and silvicultural treatments, however diversity should be encouraged.

<u>Allowable management activities in Managed and Extended Rotation Forests (Old-growth and Old Forests)</u>

Actual implementation of any of the following activities will depend on the planning and decision-making process. Once designated, direct human disturbance is limited to:

a. Salvage operations are permitted, but are subject to limits.
   - Managed: partial salvage is permitted. Up to 50% of salvageable materials, by species and size class, may be salvaged. In special cases, where significant negative impacts to forest health, forest fire protection or forest aesthetics can be demonstrated, additional salvage harvesting could be approved.
   - Extended Rotation: nearly full salvage is permitted. Some standing and downed coarse woody debris should be retained.

b. Timber harvest operations are permitted, but are subject to limits.
   - Managed: partial timber harvesting as a tool for vegetation manipulation is permitted. Examples of potentially valid reasons to cut trees include: maintaining the vigor of selected trees; enhancing composition, structure, or function; manipulating reproduction; simulating natural processes; or attempting to accomplish other management objectives (*e.g.* create a scenic viewpoint or firebreak). When merchantable trees are cut, up to 75% of the cut volume, by species and size class, may be harvested. Generally, economically low-value cut trees will be left as coarse woody debris. In special cases, where significant negative impacts to forest health, forest fire protection, or forest aesthetics can be demonstrated, additional harvesting could be approved.
   - Extended Rotation: sustainable even- or uneven-aged silvicultural systems to maintain vigorous growth, manipulate composition and structure, and produce high quality timber will be applied. As specified above, these silvicultural systems will be adapted to grow relatively larger and older trees, develop and maintain reserve trees, develop and maintain large standing and downed coarse woody debris, and encourage compositional and structural diversity.

c. Vegetation management to manipulate compositional, structural, and functional development; maintain the vigor of selected trees; and manipulate reproduction is permitted.
   - Managed: light thinning to manipulate composition (e.g. release swamp white oak), accelerate structural development, and maintain vigor of selected trees; release reproduction; create patches to stimulate reproduction; limited planting in patches and underplanting to target the regeneration of specific tree species; and occasional site preparation in patches to target the regeneration of specific tree species are permitted.
   - Extended Rotation: silvicultural practices to accomplish management goals and objectives are standard.

d. Simulation of natural disturbance processes is permitted.
   - Managed: creating patches of variable size and distribution to simulate low intensity natural disturbance is permitted.
   - Extended rotation: silvicultural practices to accomplish management goals and objectives are standard. Management practices that simulate low to high intensity natural disturbance are encouraged.

e. Fire presuppression and suppression: all necessary activities are acceptable.

f. Control of native insects and diseases: all necessary activities are acceptable.

g. Exotic organisms may be controlled and eliminated to the greatest extent feasible, while causing the minimum damage possible to the system being protected.

h. Herbivore populations may be limited to reduce negative ecological and silvicultural impacts.

i. Research activities may be facilitated to the extent desired.

j. Recreation management should be implemented. Impacts on forest composition, structure, and function should be controlled and limited. Acceptable recreational activities should be specified in the planning process and based on the achievement of management goals.

k. Infrastructure and roads should be planned and limited.

Current occurrence of Bottomland Hardwoods in the Lake States and Wisconsin

In Wisconsin, bottomland hardwood types older than 100 years represent less than 2.4% of total bottomland hardwood types acreage statewide (FIA data 2005).

Managed – Old-growth and Old Forests

The managed designation represents an innovative adaptive management paradigm. Currently, few forest stands in Wisconsin represent this combination of ecological and management requisites.

Extended Rotation – Old Forest

Although uncommon, some bottomland hardwood old forests are uneven-aged and being managed as Extended Rotation Forest.

LANDSCAPE CONSIDERATIONS

Current Conditions and Landscape Concerns

Disturbance regimes

Currently, anthropogenic disturbances are predominant in bottomland hardwood stands and landscapes. Disturbance is relatively frequent and highly variable in severity; light, moderate, and catastrophic disturbances are all common. The type, frequency, severity, and timing of disturbances, and resultant landscape patterns are drastically different than those processes which drove ecosystem dynamics prior to Euro-American settlement.

Altered disturbance regimes, especially flood pulses, have resulted in changed compositional, structural, and functional attributes within both plant and animal communities. Grazing of understory plants by domestic cattle and deer has become widespread and often intensive, and can alter species composition in stands and across landscapes. Climate change could induce significant changes in ecosystem processes.

The increasing representation of exotic invasive species could alter forest composition and function as well. Reed canary grass may totally prohibit regeneration. In addition, a dense seed bank may be present. Moderate to dense patches of common (*Rhamnus cathartica*) or glossy buckthorn also can alter regeneration and species composition. These invasive species can greatly increase in density and may prevent regeneration of several species. The loss of elm due to Dutch elm disease has lead to major changes in stand composition and structure. The potential loss of green ash due to emerald ash borer would lead to additional changes in species composition. Due to the frequency of green ash in the floodplain forests, the impacts of emerald ash borer on the structure and composition of the floodplain forests could be at least equal to the impacts of elm loss.

Landscape Composition and Structure

Altered disturbance regimes driven by anthropogenic activities (e.g. flood control dams, utilization of forest ecosystems, and land use conversion) have resulted in fragmented landscapes characterized by relatively small forest patches and abundant edges. Historical exploitation and homogeneous management regimes have resulted in decreased compositional and structural diversity. Structural characteristics of current bottomland hardwood stands and landscapes that are poorly represented include:

- Advanced developmental stages.
- Loss of large elms.
- Large old trees with large crowns and rough bark.
- Large cavity trees and coarse woody debris.
- High vertical and horizontal diversity of structural and compositional attributes.
- Large patches of relatively undisturbed older forests.
- Large woody debris in waterways.

Structural diversity provides habitat diversity which helps maintain biological diversity. Examples of the compositional impacts of fragmentation, homogenization, and simplification include:

- Increased dominance of large size class silver maple.
- Decreased representation of American elm, swamp white oak, river birch, cottonwood, and hackberry.
- Increased impacts of excessive deer browse in smaller floodplains.
- Unmanaged beaver populations can have dramatic effects on the structure and composition of old floodplain forests.
- Less microsite diversity due to controlling flood regimes.

The maintenance of biological diversity potentially could be facilitated through adaptive forest management that recognizes compositional and structural deficiencies, and which implements techniques to increase representation.

Conservation Design

The bottomland hardwood forest type: is somewhat common in Wisconsin; is a dynamic group of communities occurring on highly variable sites; is well adapted to prevailing climatic and site conditions; is well adapted to specific disturbance regimes; can occur in all developmental stages; and is a dynamic community composed of flood tolerant species. These characteristics offer the opportunity to develop and maintain significant diversity and representation in stand and landscape conditions. Management strategies that perpetuate bottomland hardwoods can range from passive, to low intensity and extensive, to intensive. A large variety of ecosystem attributes could be encouraged under different management systems.

Bottomland hardwood forests may be perpetuated in passively managed Reserved Forests (i.e. Relict, Old-growth, Old Forest) that target the development of old-growth conditions and the maintenance of biological diversity. Reserves can be small or large, but are limited by the linear nature of these systems; ecological benefits are expected to increase with increasing reserve size. Regular flood pulses and other light to severe natural disturbance events that alter forest composition and structure should be expected. A robust system of reserves will consider potential disturbance regimes and facilitate the maintenance of ecosystem representation through replication. Buffers around linear bottomland hardwood reserves can be extensively managed as Old-growth – Managed, Old Forest – Managed, and Old Forest – Extended Rotation to provide a variety of ecological and social benefits. Management of older forests also provides the opportunity to maintain corridors that connect similar stands and landscapes. Bottomland hardwood forest can play exceptionally important roles as corridors. Bottomland hardwood landscape matrix can be managed to produce social and ecological benefits by applying an array of adaptive management techniques ranging from extensive to intensive (e.g. uneven-aged, infrequently disturbed, and relatively old to even-aged with frequent disturbance and relatively short rotations).

Ecological Regions

A variety of statewide maps can help identify the ecological potential for the management of forested landscapes with significant representation of bottomland hardwoods. Some potentially useful maps are:

- *Sections and Subsections of Wisconsin* by Wisconsin DNR (2002), Appendix A, Figure A.2. This map depicts the National Hierarchical Framework of Ecological Units (NHFEU) in Wisconsin. Nested levels include two Divisions and Provinces, thirteen Sections, and forty-one Subsections (over two hundred fifty Land Type Associations are nested within the Subsections). Principal delineating criteria are climate, geology and geomorphology, hydrography, soils, vegetation, and historic disturbance regimes.
- *Ecological Regions of Wisconsin* by Wisconsin DNR (2001), Appendix A, Figure A.3. This map depicts sixteen ecoregions delineated by combining similar NHFEU Subsections.
- *Original Vegetation Cover of Wisconsin* by R.W. Finley (1976), Appendix A, Figure A.4. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is subjective and includes interpretation of survey notes.
- *Land Cover of Wisconsin Prior to Widespread Euro-American Settlement (1832-1866)* by D.J. Mladenoff and T.A. Sickley (2005 unpublished), Appendix A, Figure A.5. This map depicts the vegetation cover of Wisconsin based on data collected during the U.S. Public Land Office Surveys conducted during the nineteenth century. Data analysis is quantitative.
- *Watersheds, wetlands, soils – since BH is essentially a physiographically defined veg type, it seems that such maps would be extremely useful to locate and identify potentials*

National Hierarchical Framework of Ecological Units

The National Hierarchical Framework of Ecological Units (NHFEU) can help analyze spatial distributions and temporal potentials for landscape management applications. Provinces, Sections, and Subsections are landscape units mapped at different geographic scales and characterized by unique associations of biophysical factors (e.g. climate, topography, landform, soil, vegetation) which differentiate land areas in terms of ecological capabilities and potentials for management (Appendix A, Fig. A.2).

Province 222 was historically dominated by prairie, oak savanna, oak forests, and northern hardwood. Bottomland hardwood forests were somewhat common within this region. Sections 222 K, L, M, and R have significant areas with good biological potential for the development and management of bottomland hardwood forests. In addition, Section 212 K and Z have areas that have extensively forested bottomlands. The remainder of Section 212 generally offers only poor to fair biological potential for the development and management of bottomland hardwood old-growth forests; however, where these forests do occur they are unusual and may be particularly important to the management of landscape biodiversity. Subsections can be similarly grouped based on characteristic bottomland hardwood potential and forest extent.

Forest Habitat Type Classification System (FHTCS)

The forest habitat type classification system has not been developed for floodplain forest.

REPRESENTATIVE STANDS AND LANDSCAPES FOR ECOLOGICAL CLASSES

Relict Forest

- Avon Bottoms State Natural Areas, Avon Bottoms Wildlife Area, Rock Co. Reserved
- Richwood Bottoms State Natural Areas, Lower Wisconsin Riverway, Richland Co. Reserved
- Wauzeka Bottoms State Natural Area, Crawford Co. Reserved
- Tiffany Bottoms State Natural Area, Tiffany Wildlife Area, Buffalo Co. Reserved

Old-growth Forest – Free-Flowing River Systems

- Milwaukee River and Swamp State Natural Area, Kettle Moraine State Forest – Northern Unit Reserved
- Nelson Trevino Bottoms Federal Research Natural (SNA), Buffalo Co. USF&WS
- Mukwa Bottoms State Natural Area, Mukwa Wildlife Area, Waupaca Co. Reserved
- Rush River Delta State Natural Area, Pierce County, Reserved
- Lower Chippewa River State Natural Area – Pepin and Dunn Counties, Reserved & Active
- Farmington Bottoms State Natural Area, St. Croix National Scenic River, Polk Co., Reserved

Old-Growth Forest – Impounded Systems

- Yellow River Oxbows State Natural Area – Juneau Co. Reserved
- Lemonweir Bottomland Forest State Natural Area – Juneau Co. Reserved
- Whitman Bottoms State Natural Area, Whitman Dam Wildlife Area, Reserved

Old Forest

- No Areas Designated

LITERATURE CITED

Baker, M.E. and B.V. Barnes. 1998. Landscape ecosystem diversity of river floodplains in northwest Lower Michigan, U.S.A. Canadian Journal of Forest Research 28: 1405-1418.

Barnes, W.J. 1991. Tree populations on the islands of the lower Chippewa River in Wisconsin. Bull. Torrey Bot.Club. Vol. 118(4): 424-431.

Bayley, P.B. 1995. Understanding large river-floodplain ecosystems. Bioscience 45: 153-158.

Beatty, S.W. 2003. Habitat heterogeneity and maintenance of species in understory communities. *In*: Gilliam, F.S. and M.R. Roberts, eds. The herbaceous layer in forests of eastern North America. Oxford University Press, New York. pp 177-197

Bell, D.T. and F.L. Johnson. 1974. Ground-water level in the floodplain and adjacent uplands of the Sangamon River. Trans. Illinois State Academy of Science 67: 376-383.

Bolliger, J., L.A. Schulte, S.N. Burrows, T.A. Sickley, and D.J. Mladenoff. 2004. Assessing ecological restoration potentials of Wisconsin (U.S.A.) using historical landscape reconstructions. Rest. Ecol. 12(1):124-142

Burns, R.M. and B.H. Honkala (Tech. Coords.). 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agric. Hndbk. 654. USDA Forest Service, Wash. D.C.

Castleberry, S.B., W.P. Smith, W.M. Ford, and K.V. Miller. 2005. Herbivory and gap regeneration in southern bottomland hardwood forests. Pages 143-154 iIn: L. Fredrickson, Ed. Proceedings of the symposium on ecology and management of bottomland hardwoods systems: the state of our understanding. Univ. of Missouri Press. Columbia.

Cosgriff, R.J., J.C. Nelson, and Y. Yin. 1999. Forest Response to high duration and intensity flooding along pool 26 of the upper Mississippi River. USGS Upper Midwest Environmental Sciences Center – Project Status Report – PSR 99-01.

Curtis, J.G. 1959. The Vegetation of Wisconsin, Univ. Wis. Press, Madison, Wi. 473p.

Dahir, S.E. and C.G. Lorimer. 1996. Variation in canopy gap formation among developmental stages of northern hardwood stands. Can. J. For. Res. 26:1875-1892

Dean, T.J., and V.C. Baldwin, Jr. 1996. Crown management and stand density. In: Carter, M.C. ed. Growing Trees in a greener world: industrial forestry in the 21st century; 35th LSU forestry symposium. Baton Rouge, LA. LA Ag. Exp. Station 148-159.

Finley, R.W. 1976. Original vegetation cover of Wisconsin (map). USDA Forest Service, N. Cent. For. Exp. Stn., St. Paul, Minn.

Gergel, S.E., M.D. Dixon, and M.G. Turner. 2002. Consequences of human-altered floods: levees, floods, and floodplain forests along the Wisconsin River. Eco. Appl. 12(6): pp 1755-1770.

Hoagland, B.W., L.R. Sorrels, and S.M. Glenn. 1996. Woody species composition of floodplain forests of the Little River, McCurtain and Leflore Counties, Oklahoma. Proc. Okla. Acad. Sci. 76: 23-29.

Hoffman, R. 2002. Wisconsin's Natural Communities: how to recognize them, where to fine them. Univ. of Wisconsin Press. Madison, WI. 375p.

Knutson, M.G., L.E. MCcoll, and S.A. Suarez. 2005. Breeding bird assemblages associated with stages of forest succession in large river floodplains. Nat Areas, Jour. 25: 55-70.

Kotar, J. and T.L. Burger. 1996. A guide to forest communities and habitat types of central and southern Wisconsin. Dept. of For. Ecol. And Mgmt., Univ. of Wisconsin – Madison, Madison, Wisc.

Kotar, J., J.A. Kovach, and G. Brand. 1999. Analysis of the 1996 Wisconsin forest statistics by habitat type. USDA Forest Service, NC Res. Stn. Gen. Tech. Rep. NC-207. St. Paul, Minn. 166 pp.

Meadows, J.S. and G.J. Nowacki. 1996. An old-growth definition for eastern riverfront forests. Gen. Tech. Rep. SRS-4. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 7 p.

Middleton, B.A.. 2002. The flood pulse concept in wetland restoration. In Flood Pulsing in Wetlands: Restoring the Hydrological Balance. Pp 1-10. John Wiley and Sons, Inc.

Miller, J.R., M.D. Dixon, and M.G. Turner. 2005. Response of avian communities in large-river floodplains to environmental variation at multiple scales. Eco. Appl. Vol 14(5) pp 1394-1410.

Mossman, M.J. 1988. Birds of southern Wisconsin floodplain forest. Pass. Pigeon Vol. 50 (4) pp 321- 337.

Nelson, J.C., R.E. Sparks, and M.E. Bower. 1997. Reconstructing Lake Pepin's Natural History. USGS – Upper Midwest Environmental Sciences Center – Progress Status Report PSR 97-12.

Nelson, J.C. and R.E. Sparks. 1997. Forest compositional change at the confluence of the Illinois and Mississippi Rivers. Trans. Ill. State Aca. Sci.. 91: 33-46.

Post, D.J. 1994. The plant communities of Nine-Mile Island- Past and Present. Trans. Wis Aca, Sci, Arts, and Letters. 82: 89-108.

Schmidt, T.L. 1998. Wisconsin forest statistics, 1996. USDA Forest Service, NC For. Exp. Stn., Resour. Bull. NC-183. St. Paul, Minn. 150 pp.

Schulte, L.A., D.J. Mladenoff, and E.V. Nordheim. 2002. Quantitative classification of a historic northern Wisconsin (U.S.A.) landscape: mapping forests at regional scales. Can. J. For. Res. 32:1616-1638

Spencer, J.S., Jr., W.B. Smith, J.T. Hahn, and G.K. Raile. 1988. Wisconsin's fourth forest inventory, 1983. USDA Forest Service, NC For. Exp. Stn., Resour. Bull. NC-107. St. Paul, Minn. 158 pp.

Spetich, M.A., S.R. Shifley, and G.R. Parker. 1999. Regional distribution and dynamics of coarse woody debris in Midwestern old-growth forests. For. Sci. Vol. 45 (2) pp 302-313.

Tanner, J.T. and P.B Hamel. 2001. A long-term view of old-growth deciduous forests. In: Bottomland Hardwoods of the Mississippi Alluvial Valley: Characteristics and management of natural function, structure, and composition. USDA Forest Service General Technical Report SRS-42 Asheville, NC 109p

Tepley, A.J., J.G. Cohen, and L. Huberty. 2004. Natural community abstract for southern floodplain forest. Natural Features Inventory, Lansing, MI. 14pp.

Turner, M.G., S.E. Gergel, M.D. Dixon and J.R. Miller. 2004. Distribution and abundance of trees in the floodplain forests of the Wisconsin River: Environmental influences at different scales. Jour. Veg. Sci. 15: 729-738.

Upper Mississippi River NW&FR Draft Environmental Impact Statement/Comprehensive Conservation Plan. 2005. Appendix O.

U.S. Army Corps of Engineers Report. 1994. Tree mortality in the upper Mississippi River and Floodplain following extreme flooding. Forestry Publ. 27pp.

Wisconsin Department of Natural Resources. 1990 (2004). Silviculture Handbook. State of Wisconsin, Dept. Natl. Resour. Hndbk. 2431.5

Wisconsin Department of Natural Resources. 2001. Ecological landscapes of Wisconsin (map). State of Wisconsin, Dept. Natl. Resour., Madison

Wisconsin Department of Natural Resources. 2002. Landtype Associations of Wisconsin (map). State of Wisconsin, Dept. Natl. Resour., Madison

Wisconsin Department of Natural Resources. 2005. Wisconsin's Strategy for Wildlife Species of Greatest Conservation Need. Madison, WI.

Figure A.1. Counties of Wisconsin

Figure A.2. Sections and Subsections of Wisconsin (WDNR 2002)

National Hierarchical Framework of Ecological Units (NHFEU)
List of Map Units for Sections and Subsections of Wisconsin

200 – Humid Temperate Domain
210 – Warm Continental Division
212 – Laurentian Mixed Forest Province

212I – Lake Superior Section
212Ic – Apostle Islands Subsection

212J – Southern Superior Uplands Section
212Jb – Penokee-Gogebic Iron Range Subsection
212Jc – Winegar Moraines Subsection

212K – Western Superior Uplands Section
212Ka – Bayfield Sand Plains Subsection
212Kb – Mille Lacs Uplands Subsection

212O – Lake Michigan Section
212Ob – Green Bay Subsection

212Q – North Central Wisconsin Uplands Section
212Qa – St. Croix Moraine Subsection
212Qb – Lincoln Formation Till Plain, Mixed Hardwoods Subsection
212Qc – Lincoln Formation Till Plain, Hemlock-Hardwoods Subsection
212Qd – Rib Mountain Rolling Ridges Subsection

212T – Northern Great Lakes Section
212Ta – Green Bay Lobe Stagnation Moraine Subsection
212Tb – West Green Bay Till Plain Subsection
212Tc – Athelstane Sandy Outwash and Moraines Subsection
212Te – Green Bay Sandy Lake Plain Subsection
212Tf – Door Peninsula Subsection

212X – Northern Highland Section
212Xa – Glidden Loamy Drift Plain Subsection
212Xb – Northern Highlands Pitted Outwash Subsection
212Xc – Brule and Paint Rivers Drumlinized Ground Moraine Subsection
212Xd – Central/Northwest Wisconsin Loess Plains Subsection
212Xe – Perkinstown End Moraine Subsection
212Xf – Hayward Stagnation Moraines Subsection
212Xg – Crystal Falls Plains and Hill Subsection

212Y – Southwest Lake Superior Clay Plain Section
212Ya – Superior/Ashland Clay Plain Subsection

212Z – Green Bay-Manitowoc Upland Section
212Za – Outagamie Loamy Till and Silty Lake Plain Subsection
212Zb – Green Bay Clayey and Silty Lake Plain Subsection
212Zc – Manitowoc Till Plain Subsection

200 – Humid Temperate Domain
220 – Hot Continental Division
222 – Eastern Broadleaf Forest (Continental) Province

222K – Southwestern Great Lakes Morainal Section
222Kb – Central Wisconsin Moraines and Outwash Subsection
222Kc – Lake Winnebago Clay Plain Subsection
222Kd – South Central Wisconsin Prairie and Savannah Subsection
222Ke – Southern Green Bay Lobe Subsection
222Kf – Geneva/Darien Moraines and Till Plains Subsection
222Kg – Kenosha/Lake Michigan Plain and Moraines Subsection
222Kh – Rock River Old Drift Country Subsection

222L – North Central U.S. Driftless and Escarpment Section
222La – Menominee Eroded Pre-Wisconsin Till Subsection
222Lb – Melrose Oak Forest and Savannah Subsection
222Lc – Mississippi/Wisconsin River Ravines Subsection
222Ld – Kickapoo/ Wisconsin River Ravines Subsection
222Le – Mineral Point Prairie/Savannah Subsection

222M – Minnesota and Northeast Iowa Morainal Section
222Md – Rosemont Baldwin Plains and Moraines Subsection

222R – Wisconsin Central Sands Section
222Ra – Central Wisconsin Sand Plain Subsection
222Rb – Neilsville Sandstone Plateau Subsection

Figure A.3. Ecological Landscapes of Wisconsin (WDNR 2001)

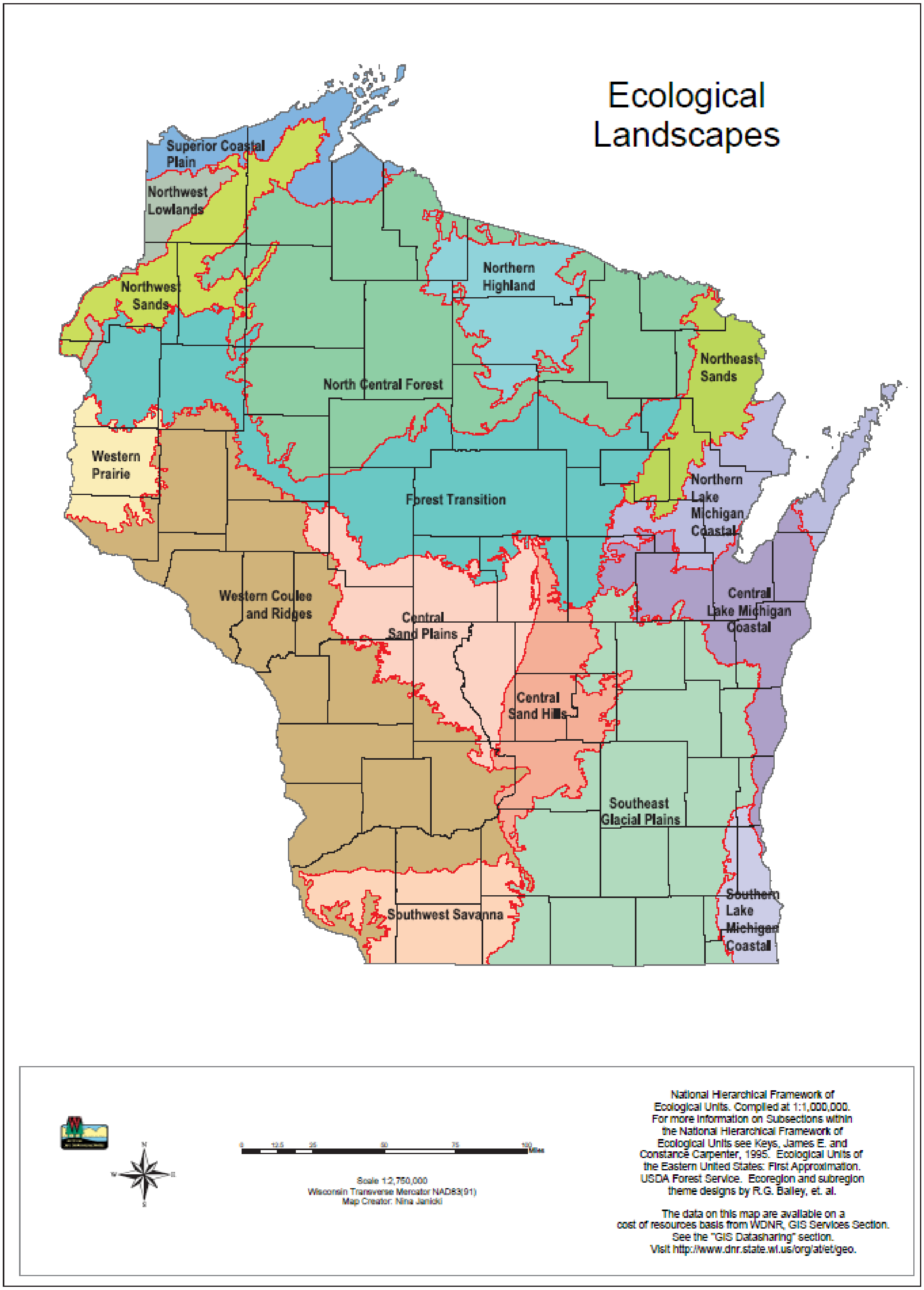


Figure A.4. Original Vegetation Cover of Wisconsin (R.W. Finley 1976)

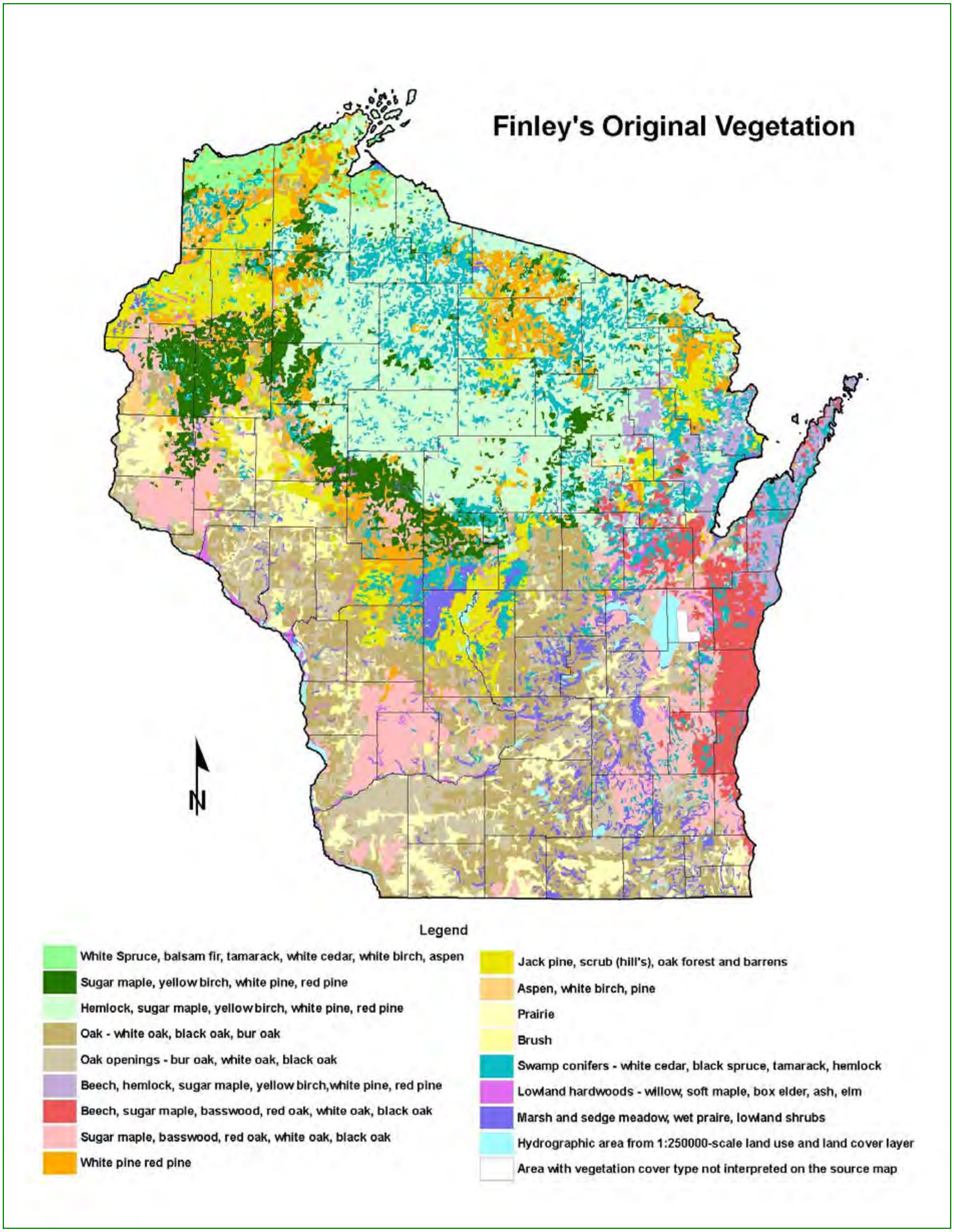
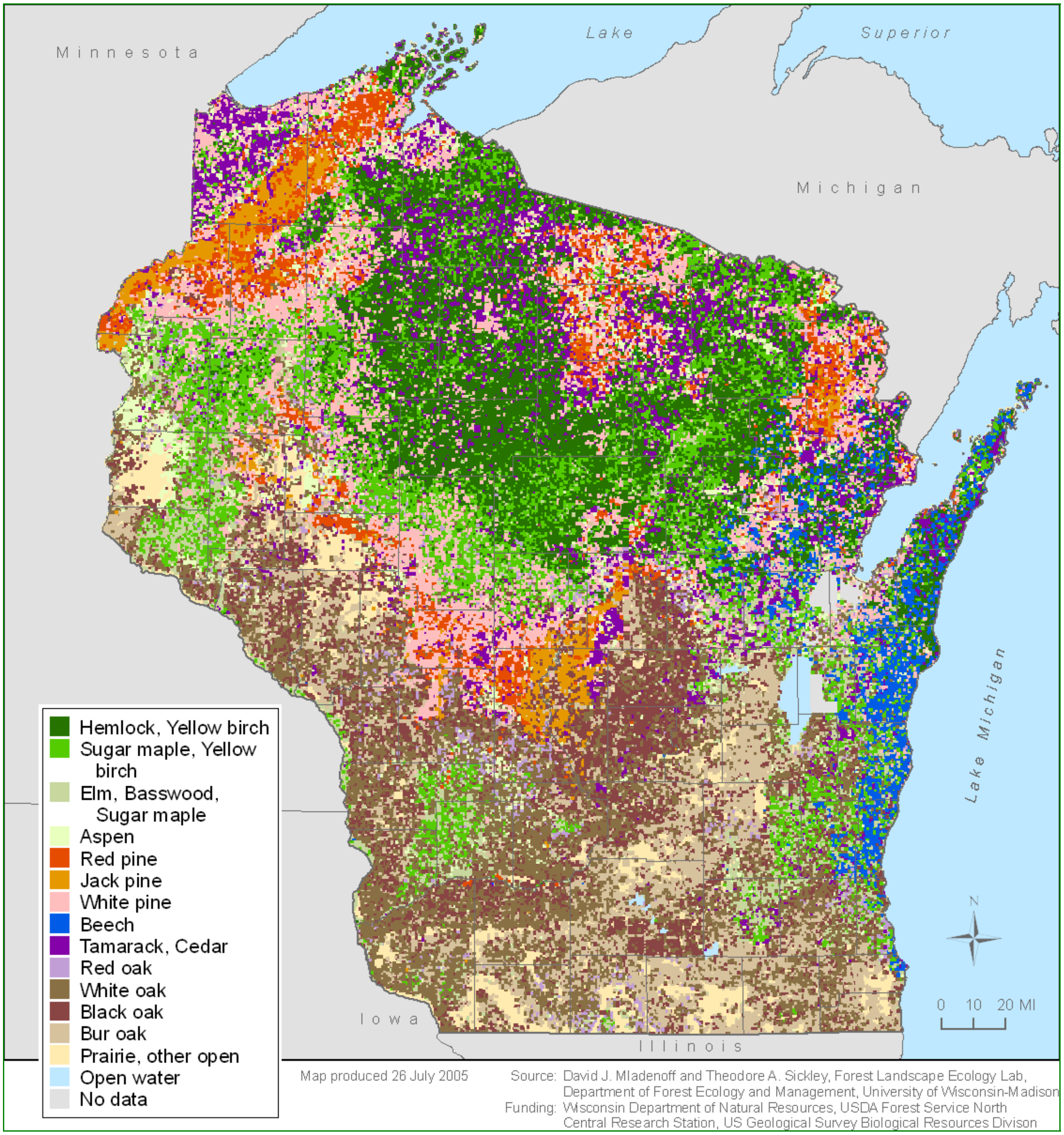


Figure A.5. Land Cover of Wisconsin Prior to Widespread Euro-American Settlement (1832-1866) (D.J. Mladenoff and T.A. Sickley, 2005, unpublished)



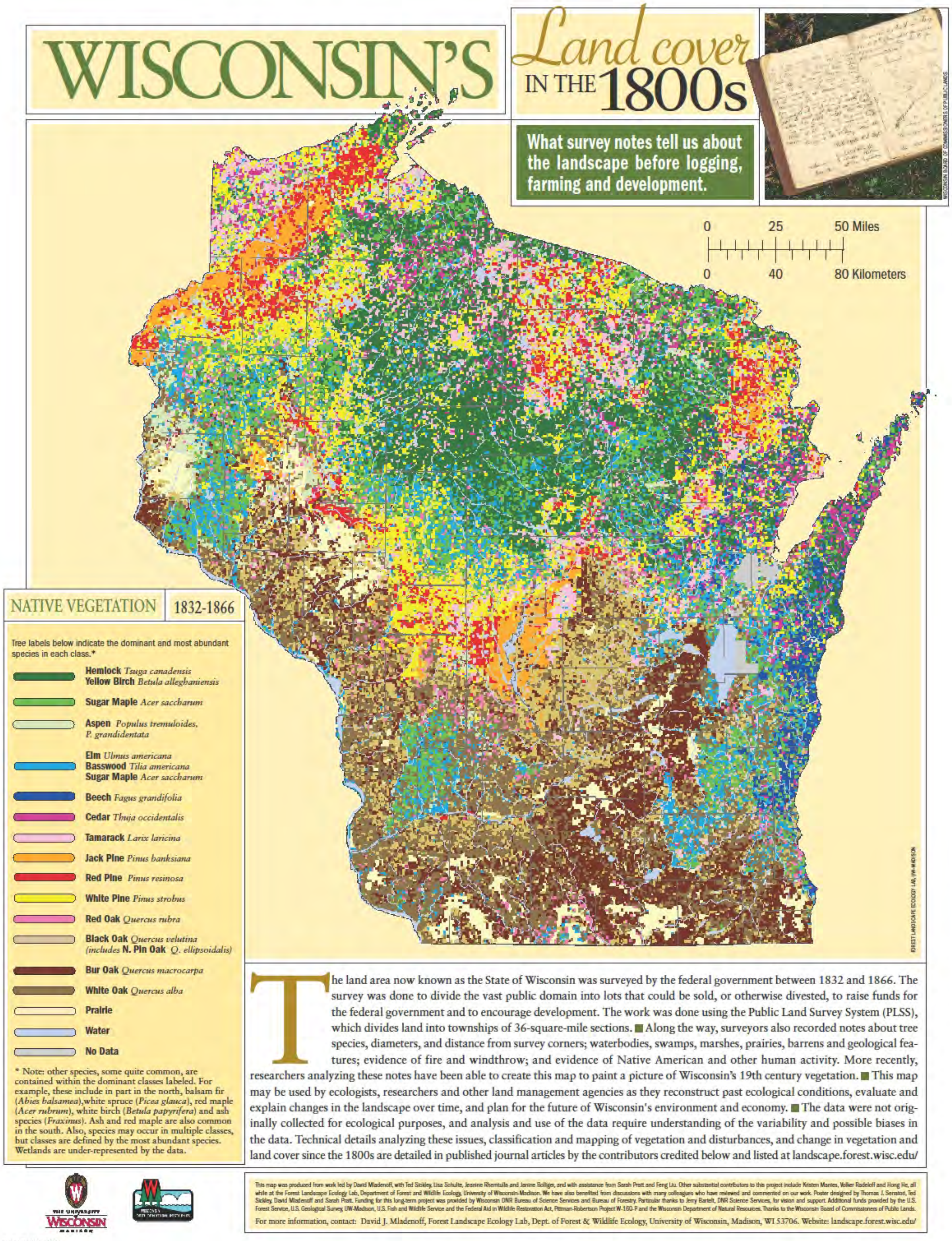


Figure A.6. Wisconsin's land cover in the 1800s (D.J. Mladenoff 2009, Wisconsin Department of Natural Resources and The University 0f Wisconsin – Madison, PUB-CE-4017)

References

Bolliger, J., L.A. Schulte, S.N. Burrows, T.A. Sickley, and D.J. Mladenoff. 2004. Assessing ecological restoration potentials of Wisconsin (U.S.A.) using historical landscape reconstructions. Rest. Ecol. 12(1):124-142

Finley, R.W. 1976. Original vegetation cover of Wisconsin (map). USDA Forest Service, N. Cent. For. Exp. Stn., St. Paul, Minn.

Schulte, L.A., D.J. Mladenoff, and E.V. Nordheim. 2002. Quantitative classification of a historic northern Wisconsin (U.S.A.) landscape: mapping forests at regional scales. Can. J. For. Res. 32:1616-1638

WDNR. 2001. Ecological landscapes of Wisconsin (map). State of Wisconsin, Department of Natural Resources, Madison

WDNR. 2002. Landtype Associations of Wisconsin (map). State of Wisconsin, Department of Natural Resources, Madison

WDNR. 2002. Sections and Subsections of Wisconsin (map). State of Wisconsin, Department of Natural Resources, Madison

APPENDIX B

Glossary of Terms[1]

Anthropogenic: Of human origin or influence.

Benchmark: 1) A point of reference from which measurements may be made. 2) Something that serves as a standard by which others may be measured.

Biological Diversity (Biodiversity): The spectrum of life forms and ecological processes that support and sustain them. Biological diversity occurs at four interacting levels: genetic, species, community, and ecosystem.

Biological Legacy: An organism, a reproductive portion of an organism, or a biologically derived structure or pattern inherited from a previous ecosystem. Biological legacies often include large trees, snags, and down logs left after harvesting to provide refugia and to structurally enrich the new stand.

Canopy (Crown) Closure: The point at which the crown perimeters within a canopy touch.

Canopy (Crown) Cover: The ground area covered by the crowns of trees or woody vegetation as delimited by the vertical projection of crown perimeters and commonly expressed as a percent of total ground area.

Cavity Tree: A (partially) hollow tree used by wildlife (e.g. roosting and reproduction).

Climax Forest: 1) An ecological community that represents the culminating stage of a natural forest succession for its environment. 2) Any forest capable of reproducing its own composition in the absence of severe disturbance. 3) A relatively stable and long-lived community that develops late in the course of vegetational development, in the absence of major exogenous disturbance, and on a specific site. It is a position of relative compositional stability, although change continues at a relatively slower pace.

Coarse Woody Debris (CWD): 1) Any piece(s) of dead woody material on the ground in forest stands or in streams. 2) Stumps and fallen trunks or limbs of more than six-inch diameter at the large end.

Codominant Crown Class: A tree whose crown helps to form the general level of the main canopy, receiving full light from above and comparatively little from the sides.

Cohort: 1) An age group of individuals. 2) A group of individuals or vital statistics about them having a statistical factor in common, such as age class. 3) A group of trees developing after a single disturbance, or a cluster of disturbances occurring over a relatively short time period, commonly consisting of trees of similar age.

Community: 1) An assemblage of plants and animals living together and occupying a given area. 2) A group of human families.

Composition: 1) The constituent elements of an entity (e.g. the species that constitute a plant community). 2) The proportion of each tree species in a stand expressed as a percentage of the total number, basal area, or volume of all tree species in the stand.

Crop Tree: 1) Any tree that the landowner wants to retain, based on landowner goals and objectives. 2) Any tree selected to become a component of a future commercial harvest.

Cutting: The felling of trees or stands.

Deforestation: The removal of a forest stand where the land is put to a nonforest use.

[1] An extensive glossary is also included in the Silviculture Handbook, 2431.5.

Demographic Transition: A stage of stand structural development, following stem exclusion and preceding old multi-aged. The crowns of the trees are now large enough so that when one dies the surrounding trees cannot fill the gap. As a result, a new cohort of trees has space to enter the canopy. Trees from the original cohort become senescent. This stage lasts from the time the first trees younger than the disturbance cohort are able to grow into the canopy until the disturbance cohort no longer has a significant presence in the stand.

Diameter (at) Breast Height (DBH, dbh): The diameter of the stem of a tree measured at 4.5 ft. (1.37 m) from the ground (on the uphill side).

Disturbance: Any relatively discreet event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

Dominant Crown Class: A tree whose crown extends above the general level of the main canopy, receiving full light from above and partial light from the sides.

Ecoregion: A contiguous geographic area having a relatively uniform macroclimate and used as an ecological basis for management or planning.

Ecosystem: A spatially explicit, relatively homogeneous unit of the earth that includes all interacting organisms and components of the abiotic environment within its boundaries.

Ecosystem Management: 1) WDNR: 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. 2) Management guided by explicit goals, executed by policies, protocols, and practices, and made adaptable by monitoring and research based on the best understanding of ecological interactions and processes necessary to sustain ecosystem composition, structure, and function over the long term.

Endangered Species: 1) A species threatened with extinction throughout all or a significant portion of its range. 2) A species whose continued existence as a viable component of Wisconsin's wild animals or plants is determined to be in jeopardy on the basis of scientific evidence.

Endogenous: 1) Intrinsic, caused by internal factors. 2) Growing from or on the inside.

Environment: The sum of all external conditions affecting the life, development, and survival of an organism.

Episodic (capricious): Occurring, appearing, or changing at usually irregular intervals.

Equilibrium: A state of balance between opposing forces or actions that is either static or dynamic. Note: In vegetation ecology, equilibrium can refer to the balance between the forces of development (structural development and succession) and diminishment (disturbance).

Even-aged Stand: A stand where the trees have only small differences in their ages (a single age class). By convention, the spread of ages does not differ by more than 20% of the intended rotation.

Exogenous: 1) Extrinsic, originating from or due to external causes. 2) Growing from or on the outside.

Exotic (Nonnative): A species introduced from another country or geographic region outside its natural range (an exotic can become naturalized, i.e. establish, grow, reproduce, and maintain itself).

Extended Rotation Forest: Old forests which are dominated by trees older than their traditional rotation age yet younger than their pathological rotation age (average life expectancy), and are managed by objective for both commodity production and the development of some ecological and social benefits associated with older forests.

Forest: 1) An ecosystem characterized by a more or less dense and extensive tree cover, often consisting of stands varying in characteristics such as species composition, structure, age class, and associated processes, and commonly including meadows, streams, fish, and wildlife. 2) An organized assemblage of trees, other plants, and animals in complex association with each other and their physical environment.

Forest Cover Type: 1) A category of forest usually defined by its vegetation, particularly its dominant vegetation as based on percentage cover of trees. 2) The plant species forming a plurality of composition across a given area.

Forest Ecology: The science concerned with the forest as a biological community dominated by trees and other woody vegetation, the interrelationships between the various trees and other organisms constituting the community, and the interrelationships between the organisms and the physical environment in which they exist.

Forest Health: The perceived condition of a forest derived from concerns about such factors as its age, structure, composition, function, vigor, presence of unusual levels of insects or disease, and resilience to disturbance.

Forest Management: The practical application of biological, physical, quantitative, managerial, economic, social, and policy principles to the regeneration, management, utilization, and conservation of forests to meet specified goals and objectives while maintaining the productivity of the forest.

Gap: The space occurring in forest stands due to individual or group tree mortality or blowdown.

Gap Dynamics: The change in space and time in the pattern, frequency, size, and successional processes of forest canopy gaps caused by the fall or death of one or more canopy trees.

Habitat: The place (environment) where an animal, plant, or population naturally or normally lives and develops.

Habitat Type: 1) A land or aquatic unit consisting of an aggregation of habitats having equivalent structure, function, and responses to disturbance. 2) An aggregation of units of land capable of producing similar plant communities at climax.

Habitat Type Classification System: A site classification system based on the floristic composition of plant communities. The system depends on the identification of potential climax associations, repeatable patterns in the composition of the understory vegetation, and differential understory species. It groups land units with similar capacity to produce vegetation. The floristic composition of the plant community is used as an integrated indicator of those environmental factors that affect species reproduction, growth, competition, and community development. A system to classify forest plant communities and the sites on which they develop.

Harvesting (Logging): The process of gathering a timber crop. It includes felling, skidding/forwarding, on-site processing, and removal of products from the site.

Herb: 1) A nonwoody, vascular plant such as a grass, a fern, or a forb. 2) A seed-producing annual, biennial, or perennial that does not develop persistent woody tissue but dies down at the end of a growing season.

Herbivory: The consumption of plants by animals.

Improvement Cutting: The removal of less desirable trees of any species in a stand of poles or larger trees, primarily to improve composition and quality.

Intermediate Crown Class: A tree whose crown extends into the lower portion of the main canopy, but shorter in height than the codominants and receiving little direct light from above and none from the sides.

Intermediate Treatment: Any treatment or tending designed to enhance growth, quality, vigor, and composition of the stand after establishment of regeneration and prior to final harvest.

Landscape: A spatial mosaic of several ecosystems, landforms, and plant communities across a defined area irrespective of ownership or other artificial boundaries and repeated in similar form throughout.

Managed (old forest management class): Designated forests (old-growth or old forests) where future active management is limited, and the primary management goal is the long-term development and maintenance of some old-growth or old forest ecological attributes within environments where limited management practices and product extraction are allowed.

Management Goal: A broad, general statement, usually not quantifiable, that expresses a desired state or process to be achieved.

Management Objective: A concise, time-specific statement of measurable planned results that correspond to preestablished goals in achieving a desired outcome.

Management Plan: A predetermined course of action and direction to achieve a set of results, usually specified as goals, objectives, and policies.

Management Policy: A definite course or method of action to guide present and future decisions or to specify in detail the ways and means to achieve goals and objectives.

Management Prescription: A set of management practices and intensities scheduled for application on a specific area to satisfy multiple goals and objectives.

Mast: Fruit and nuts consumed as food by livestock and certain kinds of wildlife.

Matrix: 1) The most extensive and connected landscape element that plays the dominant role in landscape functioning. 2) A landscape element surrounding a patch. 3) The nonreserved portion of the forest landbase. 4) A rectangular array of mathematical elements consisting of m rows and n columns.

Mature: Pertaining to a tree or even-aged stand that is capable of sexual reproduction, has attained most of its potential height growth, or has reached merchantability standards.

Mean Annual Increment (MAI): The total increment of a tree or stand (standing crop plus thinnings) up to a given age divided by that age. The culmination of mean annual increment (CMAI) is the age in the growth cycle of a tree or stand at which the MAI for volume, basal area, diameter, or height is at a maximum.

Nonnative (Exotic) Invasive Plants: Plant species accidentally or intentionally introduced from another country or geographic region, having the ability to significantly displace desirable vegetation or reduce crop yields.

Old Forest: Forests which are older than the typical managed forest (beyond traditional rotation age), but are not biologically old. They are beyond economic maturity, but are not senescent.

Old-growth Forest: Forests which are relatively old and relatively undisturbed by humans. The forest is biologically old, containing some trees which are nearing or beyond their average expected lifespan. The original even-aged overstory, established following a catastrophic disturbance, is becoming senescent, is senescing, or has senesced.

Old Multi-aged: The final stage of stand structural development. An uneven-aged forest with few or no remnants left from the original cohort. This stage will last until another stand-replacing disturbance occurs.

Overmature: 1) A tree or even-aged stand that has reached that stage of development when it is declining in vigor and health and reaching the end of its natural life span. 2) A tree or even-aged stand that has begun to lessen in commercial value because of size, age, decay, or other factors.

Overstory: That portion of the trees in a forest forming the uppermost canopy layer.

Passive Management: A deliberate decision to not manipulate forest vegetation.

Patch: 1) A small area distinct from that about it. 2) A small part of a stand or forest. 3) An ecosystem element (e.g. an area of vegetation, that is relatively homogeneous internally and differs from surrounding elements).

Pioneer: A plant capable of invading bare sites and persisting there or colonizing them until supplanted by successional species.

Poletimber: A tree of a size between a sapling and a sawtimber tree. Hardwood trees ranging in size from 5 to 11 inches dbh, and conifers ranging in size from 5 to 9 inches dbh.

Quasi-equilibrium: 1) An approximate balance between the forces of development (structural development and succession) and diminishment (disturbance). 2) The forest age-class distribution of a reference area remains stable over time, although the location and extent of developmental patches can vary. A shifting mosaic of irregular patches composed of vegetation of different ages. Patch development may or may not include successional (compositional) change. Vegetation attributes exhibit relative constancy when averaged over the entire reference area. Disturbance is part of the system, and must occur at a relatively constant rate and be of small extent relative to the size of the reference area.

Quasi Steady State: Conditions approximate a steady state and change is relatively slow.

Regeneration (Reproduction): 1) The seedlings or saplings existing in a stand. 2) The act of renewing tree cover by establishing young trees naturally or artificially.

Regeneration Cutting: Any removal of trees intended to assist regeneration already present or to make regeneration possible.

Regeneration Method: A procedure by which a stand is established or renewed by means of natural or artificial reproduction. The various methods include the removal of the old stand (usually involving a harvest), the establishment of a new one, and any supplementary treatments of vegetation, slash, or soil that are applied to create conditions favorable to the establishment of reproduction.

Release: 1) A treatment designed to free young trees (not past the sapling stage) from undesirable, usually overtopping, competing vegetation. 2) To relieve (set free) from restraint, confinement, oppression, or burden.

Relict Forest: Forests which appear never to have been manipulated, exploited, or severely disturbed by humans of European origin; in Wisconsin the stand and site should show no evidence of significant human disturbance since about 1800 AD.

Relict Old-growth Forest: Forests which are both relict and old-growth.

Reserved (management class): Designated forests (relict, old-growth, or old forests) where future active management is very limited, and the primary management goal is the long-term maintenance of relict forest or the development and maintenance of old-growth forest within a minimally manipulated environment.

Reserve Trees: Scattered, living individual trees or groups of trees left unharvested within a stand for reasons other than the purpose of regeneration. Synonyms may include leave trees, green tree retention, and standards.

Restoration: The process of returning ecosystems or habitats to their original structure and species composition.

Rotation: In even-aged silvicultural systems, the period between regeneration establishment and final cutting. Rotation may be based on many criteria including culmination of mean annual increment, mean size, age, attainment of particular minimum physical or value growth rate, and biological condition.

Salvage Cutting: The removal of dead trees or trees damaged or dying because of injurious agents other than competition, to recover economic value that would otherwise be lost.

Sanitation Cutting: The removal of trees to improve stand health by stopping or reducing the actual or anticipated spread of insects or disease.

Sapling: A usually young tree larger than a seedling but smaller than a poletimber tree. Trees ranging from 1 to 5 inches dbh.

Sawtimber: Trees with minimum diameter and length and with stem quality suitable for conversion to lumber. Hardwood trees larger than 11 inches dbh, and conifers larger than 9 inches dbh.

Seedling: 1) A usually young tree smaller than a sapling. Trees less than 1 inch dbh. 2) A plant grown from seed.

Selective (Partial) Cutting: The removal of only a portion of the trees in a stand.

Senescence: 1) The life phase of an organism, or a part of the organism, that precedes natural death, usually involving a decreased ability to repair damage and degradation. 2) The state of being old: the process of becoming old.

Shifting Mosaic Steady State: A stand or local landscape with an array of irregular patches composed of vegetation of different ages. Although individual patches cycle through changes, the proportion of different patch ages remains relatively constant over time. Also, species composition and abundance of the forest remain fairly constant over time. Development proceeds in the absence of major exogenous disturbance.

Silvicultural Prescription: A planned series of treatments designed to change current stand structure to one that meets management goals and objectives. The prescription normally considers ecological, economic, and societal constraints.

Silvicultural System: A planned program of vegetation treatment during the entire life of a stand. The three basic components are tending, harvesting, and regeneration. Named after the stand age class structure and the regeneration method employed.

Silviculture: 1) WDNR: The practice of controlling forest composition, structure, and growth to maintain and enhance the forest's utility for any purpose. 2) The art and science of controlling the establishment, growth, composition, health, and quality of forests to meet the diverse needs and values of landowners and society on a sustainable basis.

Site: 1) The sum total of environmental conditions surrounding and available to the plant. The physical (climate, topograhy, soil) and biotic (plants, animals) factors interact to yield the light, heat, water, and chemicals that are directly available and used by the plant, as well as other chemical and mechanical disturbance factors. 2) The area in which a plant or stand grows, considered in terms of its environment, particularly as this determines the type and quality of the vegetation the area can carry. 3) A spatially explicit, relatively homogeneous portion of land characterized by specific physical and chemical properties that affect ecosystem functions, and where a more or less homogeneous forest type may be expected to develop.

Site Preparation: Hand or mechanized manipulation of a site, designed to enhance the success of regeneration. Treatments may include bedding, burning, chemical spraying, chopping, disking, raking, and scarifying and are designed to modify the soil, litter, or vegetation and to create microclimate conditions conducive to the establishment and growth of desired species.

Site Potential (Site Capability): The sum total of all the factors affecting the capacity to produce forests or other vegetation. Collective physical resources (e.g. moisture, nutrients, heat, light) available for plant growth. Different potentials facilitate growth of some species and limit growth of others. Consequently, site potential has a strong effect on plant community development

Site Type: A classification of site quality or potential based on indirect measures utilizing site factors (individually or in combination) such as climate, topography, geology, soil, and vegetation. Some definitions include site index as an indirect measure of site quality.

Snag: A standing, generally unmerchantable, dead tree from which the leaves and most of the branches have fallen.

Special Concern Species: A species with some problem of abundance or distribution suspected but not proved.

Stand: 1) A contiguous group of trees sufficiently uniform in species composition, structure, and age-class distribution, and growing on a site of sufficiently uniform quality, to be considered a relatively homogeneous and distinguishable unit. 2) A contiguous group of similar plants.

Stand Density: 1) A quantitative measure of stocking expressed either absolutely in terms of number of trees, basal area, or volume per unit area or relative to some standard condition. 2) A measure of the degree of crowding of trees within stocked areas commonly expressed by various growing space ratios.

Stand Initiation: The initial stage of stand structural development, lasting from the time of stand-replacing disturbance until the new cohort forms a continuous canopy and trees begin competing with each other for light and canopy space.

Stand Structural Development: Changes in forest stand structure over time.

Stand Structure: 1) The physical and temporal distribution of plants in a stand. 2) The horizontal and vertical distribution of components of a forest stand including the age, height, diameter, crown layers, and stems of trees, shrubs, herbaceous understory, snags, and down woody debris.

Steady State: A state or condition of a system or process that does not change in time.

Stem Analysis: The analysis of a complete tree stem by counting and measuring the annual growth rings on a series of cross sections taken at different heights to determine its past rates of growth and changes in stem form, and to develop taper and volume equations.

Stem Exclusion: A stage of stand structural development, following stand initiation and preceding demographic transition. The canopy continues to have only one dominant cohort, and competition among trees is intense. Crowns are small enough so that when one tree dies, the other trees are able to fill the vacated space in the canopy by expanding their branches horizontally. The canopy is dense enough to prevent new saplings from growing into the canopy – there is no space available for new trees.

Succession: The gradual supplanting of one community of plants by another.

Suppressed (Overtopped) Crown Class: A tree whose crown is completely overtopped by the crowns of one or more neighboring trees.

Sustainability: The capacity of forests, ranging from stands to ecoregions, to maintain their health, productivity, diversity, and overall integrity, in the long run, in the context of human activity and use.

Sustainable Forest Management (Sustainable Forestry): 1) WDNR: The practice of managing dynamic forest ecosystems to provide ecological, economic, social, and cultural benefits for present and future generations. 2) The practice of meeting the forest resource needs and values of the present without compromising the similar capability of future generations. 3) The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality, and potential to fulfill, now and in the future, relevant ecological, economic, and social functions at local, national, and global levels, and that does not cause damage to other ecosystems.

Thinning: A cultural treatment made to reduce stand density of trees primarily to improve growth, enhance forest health, or recover potential mortality.

Threatened Species: A species likely to become endangered within the foreseeable future, based on scientific evidence.

Tolerance: 1) The capacity of an organism or biological process to subsist under a given set of environmental conditions. 2) The capacity of trees to grow satisfactorily in the shade of, and in competition with, other trees. 3) The ability of animals to adjust to different or disturbed habitats.

Two-aged Stand: A stand with trees of two distinct age classes, separated in age by more than 20% of rotation.

Understory: All forest vegetation growing under an overstory.

Uneven-aged Stand: A stand where the trees differ markedly in their ages, with trees of three or more distinct age classes either mixed or in small groups.

Variable Retention Harvest System: An approach to harvesting based on the retention of structural elements or biological legacies (trees, snags, logs, etc.) from the harvested stand for integration into the new stand to achieve various ecological objectives.

Viability: 1) The capacity of a seed, spore, or pollen grain to germinate and develop under given conditions. Actual viability is determined by measuring germinative capacity. 2) The ability of a wildlife or plant population to maintain sufficient size to persist over time in spite of normal fluctuations in numbers.

Vigor: Active healthy well-balanced growth.

Wildlife: All nondomesticated animal life.

Yield: 1) The amount of wood that may be harvested from a particular type of forest stand by species, site, stocking, and management regime at various ages. 2) The amount of product output recovered from a quantity of raw material input. 3) The harvest, actual or estimated, of mammals, birds, or fish expressed by numbers or weight, or as a proportion of the standing crop, over a given period.

References

Frelich, L.E. 2002. Forest dynamics and disturbance regimes, studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge, U.K.

Helms, J.A. (Editor). 1998. The Dictionary of Forestry. Society of American Foresters.

Merriam-Webster. 1977. Webster's New Collegiate Dictionary. G. & C. Merriam Co.

Nyland, R.D. 1996. Silviculture: Concepts and Applications. McGraw-Hill.

Smith, D.M. 1962. The Practice of Silviculture, 7th ed. New York: Wiley.

Spurr, S.H., and B.V. Barnes. 1980. Forest Ecology, 3rd ed. New York: Wiley.

Wisconsin Department of Natural Resources. 1995. Wisconsin's Biodiversity as a Management Issue. State of Wisconsin, Dept. of Natl. Resour., Pub-RS-915

APPENDIX C

Scientific and Common Names of Organisms Referenced

Trees
Abies balsamea -Balsam Fir
Acer negundo -Box Elder
Acer nigrum – Black Maple
Acer rubrum -Red Maple
Acer saccharinum - Silver Maple
Acer saccharum – Sugar Maple
Acer spicatum – Mountain Maple
Amelanchier spp. – Serviceberry, Juneberry
Alnus rugosa – Speckled Alder
Betula alleghaniensis - Yellow Birch
Betula nigra - River Birch
Betula papyrifera - Paper Birch
Carpinus caroliniana - Hornbeam, Bluebeech, Musclewood
Carya cordiformis- Bitternut Hickory
Carya ovata - Shagbark Hickory
Celtis occidentalis - Hackberry
Crataegus spp. - Hawthorn
Fagus grandifolia - Beech
Fraxinus americana - White Ash
Fraxinus nigra - Black Ash
Fraxinus pennsylvanica - Green Ash
Fraxinus quadrangulata - Blue Ash
Gleditsia triancanthos - Honey Locust
Gymnocladus dioicus - Coffee Tree
Juglans cinerea - Butternut
Juglans nigra - Black Walnut
Juniperus virginiana - Eastern Red Cedar
Larix laricina – Tamarack, Eastern Larch
Morus rubra - Red Mulberry
Ostrya virginiana- Hophornbeam, Ironwood
Picea glauca - White Spruce
Picea mariana - Black Spruce
Pinus banksiana- Jack Pine
Pinus resinosa - Red Pine
Pinus strobus - Eastern White Pine
Platanus occidentalis - Sycamore
Populus balsamifera - Balsam poplar
Populus deltoides - Eastern Cottonwood
Populus grandidentata - Bigtooth Aspen
Populus tremuloides - Trembling Aspen, Quaking Aspen, Popple
Prunus pennsylvanica - Pin Cherry
Prunus serotina - Black Cherry
Prunus virginiana – Choke Cherry
Quercus alba - White Oak
Quercus bicolor - Swamp White Oak
Quercus ellipsoidalis - Northern Pin Oak
Quercus macrocarpa - Bur Oak
Quercus muehlenbergii - Chinkapin Oak
Quercus rubra - Northern Red Oak
Quercus velutina - Black Oak

Salix nigra - Black Willow
Sorbus americana - Mountain Ash
Sorbus decora - Showy Mountain Ash
Thuja occidentalis - Northern White Cedar
Tilia americana – Basswood, Linden
Toxicodendron vernix - Poison Sumac
Tsuga canadensis - Eastern Hemlock
Ulmus americana - American Elm
Ulmus rubra - Red Elm, Slippery Elm
Ulmus thomasii - Rock Elm, Cork Elm

Herbaceous Vegetation
Dicentra canadensis - Squirrel Corn
Dryopteris goldiana - Goldie's Fern
Dryopteris intermedia - Intermediate Wood Fern
Medeola virginiana - Cucumber-root
Oxalis montana - Violet wood sorrel
Panax trifolium - Dwarf Ginseng

Mammals
Martes americana - American Marten
Odocoileus virginianus - White-tailed Deer

Birds
Catharus ustulatus - Swainson's Thrush
Certhia americana - Brown Creepers
Chaetura pelagica - Chimney Swift
Dendroica caerulescens - Black-throated Blue Warbler
Dendroica cerulea - Cerulean Warbler
Dendroica virens - Green Warbler
Empidonax virescens - Acadian Flycatcher
Troglodytes troglodytes - Winter Wren
Wilsonia citrina - Hooded Warbler

Herpetiles
Plethodon spp. – Plethodontid Salamanders

Fungi
Cristinia muscida

APPENDIX D

CHEQUAMEGON-NICOLET NATIONAL FOREST
OLD-GROWTH FOREST AND OLD-GROWTH ALLOCATIONS
IN THE 2004 FOREST PLAN

Old-growth

Traditionally, the term *old growth* has been used to describe remnant original forest although other types of relatively old forest are recognized as old growth such as those communities with dominant trees at or near biological maturity (WDNR 1995) (*see also* Wisconsin Department of Natural Resources 1996). In Wisconsin, representative old growth forests are those that were not cut over during the period of logging in the late 1800's and early 1900's. Original forest conditions are characterized by older trees, trees with cavities, and sizable coarse woody debris (Parker 1999). Intrinsically, remnants are finite; they cannot be created. They remain as a reference of community composition in pre-settlement times with some exceptions, such as the absence of those animal species that require areas greater than that which the old growth area provides. These old growth areas give the clearest representation of ecosystem function prior to settlement by Europeans.

Today, definitions of old growth abound and all have limitations. Most rely on a set of ecological attributes that describe old growth in relative terms (WDNR 1996) (Table 1). Hunter (1989) proposed that old-growth forests should be conceptually defined as **relatively old** and **relatively undisturbed by humans** and that a more precise definition can be devised on a regional or even stand-specific basis.

Table 1. Ecological attributes currently used to define old growth and the most common qualities of those attributes in old growth definitions.

Ecological Attributes*	Old growth qualities
Successional Development	Dominant tree species to be at a climax or late-successional stage
Disturbance History	Stand characteristics are the result of absent or limited human disturbance
Age Characteristics	Age at which tree species composition has stabilized or the age where the dominant trees have reached their life expectancy
Forest Structural Characteristics	Highly heterogeneous age class distribution with all age classes represented, tip-up mounds present, variable sized canopy gaps, plentiful standing and down coarse woody debris
Landscape Distribution	Shifting mosaic of developmental stages dependent on a natural disturbance regime
Ecosystem Function	Ecological processes associated with undisturbed ecosystems predominate

* Adapted from Wisconsin Department of Natural Resources (1996).

In 1992 the Forest initiated a survey to identify the most significant natural areas on the Forest. For the purposes of the inventory, natural areas are defined as those tracts of land or water so little modified by human activity, or which have sufficiently recovered from the effects of such activity, that they contain intact native plant and animal communities believed to be representative of the State's pre-EuroAmerican vegetation (Scientific Areas Preservation Council and Wisconsin DNR 1983). Thus, the Forest's natural area inventory has identified the most exemplary natural communities of the Forest. These areas include existing and "best potential" old growth. The term "best potential" refers to sites that are of high ecological value (based on the composition, structure, and function of the site) but are not presently old enough to be classified as old growth. Under the proposed Forest Plan, these areas are represented by Management Area (MA) 8G as well as some Existing and Candidate Research Natural Areas (MA 8E) and Special Management Areas (MA 8F).

Developing Old-growth

Relict forest communities cannot be created but communities that approximate these old growth conditions can be restored in areas where the species composition, land use patterns, or other ecosystem characteristics are amenable. Areas designated by MA 5, 5B, 6A and 8D, through limited human impacts in them, are expected to progress towards conditions representing old growth communities. To achieve those conditions (species composition, community structure, and ecosystem function), activities such as removal of non-native invasive or undesirable native species or prescribed burning may be required. These areas can be considered "developing old growth."

Allocations To Old-growth And Developing Old-growth

Based on the recommendations of the *Analysis of Management Situation: Old Growth Forests* (USDA-Forest Service 2000), old growth allocations on the Chequamegon-Nicolet National Forest should not exceed 68%, the average percentage of land in old growth conditions in the Lake States during the stable historic period (Frelich & Lorimer 1991). Frelich & Lorimer (1991) estimated that, on average, at least 40% of the forested land in the Lake States during the 3000-year stable historic period was in old growth conditions (132-160 years old). Forty percent of the forested land on the Chequamegon-Nicolet National Forest amounts to 527, 545 acres. Although the lower limit of old growth necessary to fulfill ecosystem function is unknown, the *Analysis of Management Situation: Old Growth Forests* (USDA-Forest Service 2000) suggests that a third to a half of that acreage (or 13-20% of the total forested land) be allocated to old growth and areas that are expected to progress toward old growth conditions.

Old-growth Allocations

The 2004 Forest Plan allocates 244,200 forested acres to old growth and to areas where there will be future development of old growth. These acres are located in Research Natural Areas, Special Management Areas, Old Growth Management Areas, designated Wilderness Areas, and areas recommended for Wilderness designation. Management Areas allocated to old growth amount to 19% of the forested acres on the Chequamegon-Nicolet National Forest.

References

Frelich, L.E. & C.G. Lorimer. 1991. A simulation of landscape-level stand dynamics in the northern hardwood region. Journal of Ecology 79:223-233.

Hunter, M.L. 1989. What constitutes an old-growth stand? Journal of Forestry 87:33-35.

Parker, L. 1999. Landscape analysis and design on the Chequamegon-Nicolet National Forest: Draft Report. USDA-Forest Service, Park Falls, Wisconsin.

Scientific Areas Preservation Council and Wisconsin Department of Natural Resources. 1983. Scientific Areas long range plan. Madison, WI.

USDA-Forest Service. 2000. Analysis of Management Situation: Old Growth Forests. Unpublished.

Wisconsin Department of Natural Resources. 1995. Wisconsin's biodiversity as a management issue. State of Wisconsin, Dept. of Natl. Resour. Pub-RS-915.

Wisconsin Department of Natural Resources. 1996. Old growth and mature forests in Wisconsin; technical considerations for landscape management. DRAFT. State of Wisconsin, Dept. of Natl. Resour.

Rev (MJS) Jan 21, 2004; modified by R.G. Eckstein Jan 11, 2006