Appendix D
General Assessment of Historic Range of Variability

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Introduction

Ecosystems at all scales are constantly undergoing change. Changes at grand scales, such as global warming or cooling or physical events like volcanic eruptions, restructure entire ecosystems. However, during periods of relative climatic and physical stability, changes are small and fall within a definable range sometimes referred to as the "range of natural variability."

"Range of natural variability" (RNV) is a term used to reference the variation of physical and biological conditions within an area due to climatic fluctuations and disturbances of wind, fire, and flooding. In the United States, it has been defined as the variability in composition, structure, and dynamics of ecosystems before EuroAmerican influence (Swanson et al. 1994). This range is determined by studying the ecological history of the area in question. It is intended to provide a description of historical conditions to be used as a baseline for comparison with current conditions to assess the degree of change that has occurred, and to predict the amount of additional change that will occur under different management options. It gives some indication of the sustainability of ecosystems and identifies some compositional, structural, and functional components of ecosystems which may need management attention. It can help in developing management alternatives by indicating where adjustments can be made to improve forest diversity and health. Managing an ecosystem within its RNV is a way to provide a coarse-filter for biological diversity and meet many of the legal and regulatory requirements for maintaining viable populations of native species.

Development of the description of RNV does not imply that the Chequamegon-Nicolet National Forests (CNNF) intend to return the area to historical conditions; indeed, it is impossible to do so and may be undesirable within the context of achieving multiple-use objectives. The purpose of examining historical conditions is to identify ecosystem factors that formerly sustained species and communities that are now reduced in number, size, or extent, or which have been changed functionally. Maintaining or restoring some lands to closely resemble historic systems, and including some structural or compositional components of the historic landscape within actively managed lands, can help conserve important elements of biological diversity.

Assumptions and Limitations of RNV

Our ability to describe RNV is limited by availability of information on past landscapes. We draw information from research findings and descriptive records of historical conditions, and on information from recent times regarding natural disturbances of fire, wind, or flooding. The quality of the information varies depending on the geographic area in question, the time frame, and the type of disturbance. Thus, in this document some inferences are made based on information from other areas, and some portions of RNV descriptions will remain incomplete till further research is available.

A basic assumption central to the application of RNV is that species are adapted to certain environmental conditions and can tolerate or may even require a range of disturbances similar to those which existed during their evolutionary period (see discussions of evolutionary biology and evidence supporting its premises in many basic textbooks, such as in Chapter 7, “Environment and adaptation: some examples”, in Ricklefs (1979)). Loucks (1970) has noted that genetic differentiation within major forest genera occurred between 30 million and 2 million years ago, and it was at this time that one or more species in each genus adapted as “opportunists” capitalizing on different kinds of disturbances, and on conditions of deep shade in closed forest systems. This is why “most species will generally be adapted to those disturbance regimes that have historically dominated an area” (Alverson et al. 1994). Many of our current species are known to depend on natural disturbances to complete portions of their life cycles, for example, jack pine trees have serotinous cones which open in fire and release seeds for germination and stand regeneration (Rudolph 1985). Information on the type, frequency, severity, and spatial arrangement of natural disturbances is needed to manage for these disturbance-dependent species.

In the historic landscape, natural disturbances were responsible for initiating cycles of succession; in other words, a fire, wind, or flood disturbance would destroy all or part of the vegetation on an area. Then, the area would be colonized by early successional species, and if it were not re-disturbed by fire, wind, or flood, it would gradually change to late-successional species and eventually become old growth. Some patches within a broader area would have been affected by disturbance more frequently than others, partly due to random chance, and also because some areas are more susceptible to disturbance. Areas with shallow water tables, or high exposed ridges, are more likely to be disturbed by wind. Large, flat, sandy areas are more likely to experience catastrophic fire than smaller areas. The condition of the historic landscape, in terms of forest composition and age structure, was a direct result of these natural disturbances.

The time frame used for describing RNV is chosen based on certain factors; for this analysis, a period of similar climate and species presence as exists in current times was chosen. Because species migrated northward at different rates after Pleistocene glaciation, community composition was unstable for some time after major climatic trends had stabilized. At about 3,000 years ago, today’s forest species were present in the northern Wisconsin-western Upper Michigan area, and the climate had stabilized after a major shift in the mid-Holocene (Davis et al. 1993, Webb et al. 1993). Thus, the period beginning 3,000 years before present was selected as an appropriate time frame for analysis of RNV.

There is also a question as to what level of human activity might be within the RNV. Plant and animal species of our continent evolved without the presence of humans until approximately 10,000 years ago. While many species are tolerant of a human presence, and some ecological functions are resilient to human-caused disturbance, there is evidence that other species and functions are harmed by human activity. In many cases, activities believed to be relatively benign have had negative effects, particularly when taken in combination. For example, it is now generally accepted that the widespread forest declines in central Europe are due to a number of partly interacting stresses, some of which are human-caused (Larsen 1995, Fuhrer 1990). These include pollution stresses together with the effects of forest management, including a lack of genetic and species diversity in forest stands; nutrient export in harvesting and leachate; reductions in soil moisture infiltration and storage due to soil compaction; declines in ground vegetation cover; and declines in mycorrhiza and beneficial soil microorganisms. The combination

of these stresses makes trees vulnerable to naturally occurring insect pests, as well as fungal, viral, and bacterial infections that healthy forests would be able to withstand. Other effects of human disturbance include declines in populations of many species. Current estimates indicate that 20 percent of species (globally) may become extinct in the next 40 years, "an event that would rival the greatest geological extinction episodes" (LaRoe 1993). Hunter (1996) states that benchmarks by which we evaluate the structures and functions of ecosystems should be "without human influence." This reasoning was used in compiling information about range of natural variability. Human activity is not included in benchmark descriptions because some species and ecological processes are adversely affected by human disturbance.

Geologic History of the Northern Wisconsin and Western Upper Michigan Area

Multiple glaciations have occurred within the area during the past 2.5 million years. The Wisconsin glaciation began about 70,000 years ago. After numerous advances and retreats, a final advance began about 22,000 years ago, reached its maximum at about 18,000 years ago, and melted back to expose the Pleistocene sediments of our area about 10,000 years ago. Glacial features were formed by the ice sheet, and by subsequent melting and water and wind movement of materials left behind. The resulting formations include drumlins, ground and end moraines, eskers, kames, kettles, heads-of-outwash, pitted and unpitted outwash plains, fans or deltas, and lacustrine plains (Pielou 1991; Stearns 1997a). These features are the basis for Landtype Associations (LTAs), a level within the ecological land classification system used to map and characterize areas that function similarly at the landscape scale (ECOMAP 1993).

Because LTAs are usually comprised of a single glacial feature with the same source material and surface shape, the soil, hydrologic, and microclimatic conditions within a LTA are similar. The physical composition of these glacial features is a "major control on the spatial distribution of vegetation (Stearns 1993) when broader-scaled climatic conditions are relatively stable (Graumlich and Davis 1993). Certain kinds of disturbance (fire, wind, and flood) are associated with specific vegetation types, as noted by Pastor and Mladenoff (1991) in the comparison of boreal and northern hardwood forests. Specific vegetation types are associated with certain LTAs. The association of LTA, vegetation, and disturbance type helps us predict which disturbances, with which severity and frequency, occurred on different land areas in historic times, and what the landscape pattern of successional patches would have been like.

Climate During the Holocene

Climatic fluctuations have occurred during the past 10,000 years (Pielou 1991). The general trend in the Midwest was one of rising temperatures after deglaciation until about 6,000 years ago (estimates of dates vary among experts) and then a gradual cooling. Warmest and driest conditions occurred at about 6,000 years ago, and since about 4,000 years ago more humid conditions have prevailed. Dates of major climatic shifts have been identified by studies of fossil pollen, and corroborated by studies of changes in lake levels (Webb et al. 1993). Corresponding changes in the "tension zone" between biomes of mixed prairie-forest vegetation and deciduous forest were documented by Webb et al. (1983) based on fossil pollen analysis. By 3,000 years ago, "most of the lake sites in eastern North America ... [had] water levels characteristic of today, and were similar to the present in terms of effective moisture." (Webb et al. 1993). Minor fluctuations since then include the Little Climate Optimum that peaked at about 1,800 years ago, during which conditions were warmer than at present. During the Little Ice Age, which occurred

between about 1450 to 1850 A.D., the climate was cooler, wetter, and stormier than previously (Stearns 1993). Climate change seems imminent today at a global scale, but there is no indication of the direction or magnitude of the predicted climate change in northern Wisconsin at this time.

Stability and Change in Vegetative Communities

Following the retreat of Wisconsin glacial ice sheets, tree species moved northward and westward at different rates from their glacial refugia in the south and southeastern U.S., as evidenced by fossilized pollen grains retrieved from sediment core samples. Migration rates of individual species varied due to differences in their dispersal and survival mechanisms and competitive abilities, as well as their tolerance of diseases. In general, species with wind-dispersed seeds and the ability for primary colonization on disturbed sites were able to move more quickly in response to changing climatic conditions. Boreal species were the first trees to survive in northern Wisconsin after deglaciation because climatic conditions were still very cold. Approximate dates when various tree species reached northern Wisconsin have been compiled by Stearns (1993) based on works by Davis (1981) and Swain (1978), and are shown in the following table.

Table D-1. Common tree species in northern Wisconsin and their approximate time of migration into the area during the Holocene.

Tree species	Approximate time of arrival in northern Wisconsin (years before present)
Tundra/spruce woodland, larch	13,000 to 10,000
Jack pine, red pine, birch, oak	10,000 to 8,000
White pine, sugar maple, yellow birch	8,000 to 3,500
Hemlock	3,500 to present

Changes in relative abundance of species within the forest have been related to major climatic differences between the early and late Holocene, as well as to minor climatic fluctuations within the late Holocene, as evidenced by studies of pollen in sediment cores. Sediments deposited during the mid-Holocene are dominated by pollen of white pine, oak and red maple at Sylvania, Michigan. A major transition occurred around 3000 years ago, at which time pollen from yellow birch, then hemlock, and finally sugar maple and basswood increased in abundance (Davis et al. 1993). Since that time, the composition of forest tree species has been relatively stable (Webb et al. 1983), although minor climatic fluctuations resulted in some shifts in dominance of species. During the Little Climate Optimum, which peaked at about 1,800 years ago, conditions were warmer than at present. At that time, forest fires were more common in northern Wisconsin and forests contained more paper birch, aspen, oak, and pine as a result (Stearns 1997b). During the Little Ice Age, from about 1450 to 1850 A.D., it is postulated, “many large hemlock stands were established...after catastrophic windstorms followed by fire exposed mineral soil.” (Davis et al. 1993 quoting Forest Stearns).

Natural Disturbance Regimes of Fire, Wind, and Flooding

The description of natural disturbance regimes of fire, wind, and flooding, and their consequent patterns of successional patches in the landscape, has been studied at various places in the Lake States. A summary of this information applied to northern Wisconsin landscapes helps describe changes in the current landscape, and develop and evaluate alternatives relative to the likely effects on biological diversity in the future landscape.

Large areas of northern hardwood-hemlock forests in which wind was the primary disturbance factor dominated the historic landscape matrix in northern Wisconsin. Fire was relatively uncommon in these forests. Smaller patches of boreal forest and pine barrens and small and medium patches of pine forests were affected most by fire. Areas adjacent to small and large streams and rivers were affected most frequently by flood events (Finley 1976; Frelich 1995).

Fine-scale Wind Disturbance

Frequent, fine-scale wind disturbance created small canopy gaps throughout the primary forests of the Lake States. Canopy gap disturbance was the most spatially extensive disturbance in the hemlock-hardwood forests. Canopy gaps are formed when strong winds associated with thunderstorms or strong winter storms, sometimes in combination with ice or snow loads, topple trees or break off large branches or treetops. Often, a falling tree will topple several of its neighbors, creating an opening in the forest canopy. In this review, the measurements reported are based on a definition of the canopy gap as the land area directly under the canopy opening. While large, catastrophic wind events were more dramatic, they were infrequent and impacted only about a tenth of the area of fine-scale wind disturbances (Canham and Loucks 1984). The rate of wind disturbance (area impacted annually) and the size distribution of canopy gaps (how many in each diameter class) are measures that show the extent to which the structure and composition of the original hemlock-hardwood forest was shaped by wind.

Work by Frelich and Lorimer (1991) in Upper Michigan shows that the rate of canopy gap disturbance was 0.57 percent to 0.63 percent (of the area of primary forests annually). There is no equivalent analysis for northern Wisconsin forests, but the comparable nature of the landscape and climate suggest that rates were probably similar in forests of northern Wisconsin.

Two studies conducted in the Lake States included direct measurements of gap size distribution in old-growth forested stands (Tyrrell and Crow 1994, Dahir and Lorimer 1996). Additionally, one study was conducted in the eastern U.S. in stands of similar species composition (Runkle 1982). Measurements from these studies were compared. Dahir (1995) measured gaps in the Porcupine Mountains using permanent plots totaling 9.88 acres and measurements taken over 11 years. Runkle and Tyrrell's studies were conducted using transects over a greater area, a method which captures larger gaps. Runkle's (1982) study showed that larger gaps formed more infrequently, so that the maximum gap diameter expected on 9-10 acres in 10 years would be 52 feet. Dahir and Lorimer's study lasted only 11 years and had a total plot size of less than 10 acres, so they would not expect to find large gaps. This may explain why the largest gap found in Dahir and Lorimer's study was 42 feet in diameter. The size distribution of smaller gaps corresponded closely with results of Tyrrell (1991) (see comparison in Table 2.).

Tyrrell (1991) measured gaps using the transect method in 25 old-growth hemlock-hardwood forest stands in the Lake States. She found distinct differences in number and size of canopy gaps in very old forests of 275-300 years as compared with stands 177-274 years of age. Table 2 shows Tyrrell's data for the 8 stands aged 275 years or older. Gaps of size greater than 74 feet in diameter were not reported separately in her study, but other size classes can be compared directly with Runkle's results (1982). Tyrrell found a greater percentage of gaps in the smaller size classes and a lower percentage in the very largest classes, but the central part of the size distribution is very similar. The reason for these differences is likely that Runkle's sampling method missed many gaps in the smallest classes. The difference is probably not due to species composition of the

sites; Dahir (1995) provided evidence that there were no significant differences in mean gap sizes between hemlock and hardwood stands. Thus, there are shortcomings in our ability to extrapolate and apply the data from both Runkle's and Dahir's studies. Thus, Tyrrell's data offers the best estimate of actual canopy gap size class distribution for this area.

The information on canopy gap disturbance for the mesic forests of the Lake States is summarized in Table 2. Tyrrell's (1991) gap size distribution measurements and Frelich and Lorimer's (1991) rate of impact estimates were used to calculate size distributions of areas impacted annually. A combination of Runkle (1982) and Tyrrell's (1991) data was used to estimate proportions in the three largest size classes.

Table D-2. Canopy gap size distributions and area impacted for each size class, based on work by Tyrrell (1991), Frelich and Lorimer (1991), and Runkle (1982), and including information from Dahir (1995).

Gap diameter[1]		Gap size[1]	% of gap-disturbed area in gaps this size class*			Area impacted at rate of 0.57 - 0.63%[4]	Return period for this size gap to recur on a specific acre [5]
ft	acres	ft^2	Runkle	Tyrrell[2]	Dahir[3]	ft^2 /acre / yr)	yrs
12	.002	113	-	20.4	13	50.7-56.0	2
18	.006	269	9.4	16.8	23.5	41.7-46.1	6
26	.012	538	10.9	20.8	27.5	51.6-57.1	9-10
32	.018	807	11.7	13.9	21	34.5-38.1	21-23
37	.025	1076	20.2	5.8	6	14.4-15.9	68-75
45	.037	1615	14.4	10.2	>10	25.3-28.0	58-64
52	.049	2153	8.6	2.2	-	5.5- 6.0	359-392
74	.099	4306	13.5	7.1	-	17.6-19.4	222-245
98	.173	7535	7.4	(est) 2.0	-	4.9-5.5	1370-1537
117	.247	10764	1.4	(est) 0.4	-	0.9-1.0	10350-11574
143	.371	16146	2.1	(est) 0.6	-	1.4-1.6	10185-11213
Total						248.3-274.4	

1 The size class is represented by the maximum sized gap found in that class.

2 Tyrrell (1991) data is the average size frequency distribution of canopy gaps in the eight oldest stands (among 25 stands in the study). Taken from the table in Appendix XV, page 184. Size classes were not reported separately for gaps with diameter greater than 74 feet.

3 Dahir (1995) data is taken from Figure 3.1, page 66. Values represent the average size frequency distribution of canopy gaps in five plots in old-growth hardwood and hemlock forests. Numerical values were estimated from the chart and interpolated between size classes to correspond with Runkle's (1982) and Tyrrell's (1991) size classes.

*4 Rate estimate is from Frelich and Lorimer (1991). Calculations: total area disturbed*percentage as a fraction using Tyrrell's (1991) data, taken for each size class. Reported as a range in area disturbed based on the range in rate of disturbance. Additional decimal places were used in the calculations.*

5 Calculations: for each size class [gap size (sq ft)/area impacted annually (sq ft/acre/yr)] = number of years that on average are required to get a gap of that size class on a given one acre area. Additional decimal places were used in the calculations.

Catastrophic Wind Disturbance

Catastrophic windthrow disturbed an average of 0.07 percent of the hemlock-northern hardwood forests of northern Wisconsin each year according to early survey records (Canham and Loucks, 1984). This disturbance rate is taken from their estimates of 4,828 hectares as an average annual area of disturbance, divided by the total 6,560,000 hectares of hemlock-hardwood forest estimated to have existed during early European settlement times. Mean patch size of blowdown areas was 230 acres. The orientation and distribution of the blowdown patches noted in the survey records indicate, "several major and many smaller storms were responsible for the disturbance pattern." An approximate patch size distribution for these large disturbances is shown in Table 3.

Table D-3. Patch size distribution for catastrophic wind disturbance in hemlock-northern hardwood forests of northeastern Wisconsin.

Patch size (acres)	Percent of total patch disturbance area (within 0.07% of a large area) in patches this size*	Example for a 1 million acre area: acres disturbed annually for each size class
2.5-25	31.09%	218
25-250	30.37%	213
250-2500	25.59%	179
>2500	12.95%	91

** Values in the second column are the percentages of all patches that fell within the size ranges shown in the first column, based on the sum of all catastrophic wind events recorded in the study area (0.07% annually, or 700 acres out of 1 million). Adapted from Canham and Loucks (1984).*

These wind-disturbed patches contained all the woody debris from fallen tree trunks and branches, as well as tip-up mounds where whole trees had been blown over. These features are likely not as common or widespread in today's forests. Tip-up mounds and large logs are known to have provided sites for regeneration of some forest species, particularly hemlock (Mladenoff and Stearns 1993). The large woody debris may have been a deterrent to deer herbivory as has been shown for deer and elk in the West (Wallmo 1969; Lyon 1976). Certain ground-flora and shrub species were likely to have prospered in these areas with higher light, exposed mineral soil, and the relative protection afforded by the large woody material. Early survey records make note of the great difficulty of traversing such areas, strewn with fallen trees and "overgrown with hazel" as well as other bushes and small trees (Stearns 1949). The hemlock-hardwood forests were generally quite resistant to fire, but fire did occur in these openings, especially when droughty conditions dried the woody debris. (Stearns 1949) These fire events in catastrophic blowdown areas may have facilitated establishment of white pine forests in areas where soils and landforms typically give a competitive advantage to northern hardwoods. Graham (1941) conducted a forest history study that documented the establishment of where white pine forests in Upper Michigan following a period of drought and fires in the 16th century.

Wind Disturbance: Age-class Distributions

Frelich and Lorimer (1991) studied disturbances of wind and fire to determine how the original forest of the Lake States was distributed among various age classes. The study was conducted in three large tracts of hemlock-hardwood primary forest in Upper Michigan, including Sylvania, the Porcupine Mountains, and the Huron Mountains. The average rate of gap formation was 5.7 to 6.9 percent per decade (the range depends on the accuracy of the estimate). They also found that there was a relatively uniform distribution of patch ages, because large disturbances (downbursts) were rare, and light and moderate disturbances were probably caused by thunderstorms, the number of which does not vary much among decades. Also, recently disturbed areas were less susceptible to disturbance for several decades afterwards. Wind speed data collected from weather stations in the study area indicated that wind speeds of 100-120 km/hr recurred at intervals of only a few years; there were 5 events with winds above 140 km/hr and 2 events above 160 km/hr out of 472 station-years. Wind speeds of >200 km/hr cause heavy destruction, but those in the study area caused only partial destruction. Fires were uncommon in hemlock-hardwood forests.

Runkle (1982) studied sites in North Carolina, Tennessee, Ohio, Pennsylvania, and New York. These were forested dominantly with sugar maple and beech, and included some hemlock, basswood, and southern hardwood species. Runkle (1982) was interested in the question of why average return intervals for disturbance could be considerably shorter

than the known life span of these trees. He found that some individuals at some locations were able to live longer than average because “gaps can occur on one site several times before they occur on a second site,” which would leave part of the area undisturbed for a long period of time.

Runkle (1982) developed an algebraic equation to calculate the fraction of an area that would not have been affected by disturbance within a certain length of time. The equation uses locally derived input variables and so is applicable in any region. It operates under the assumption that the probability of any point undergoing disturbance is random, an assumption that in some cases is not true. Frelich and Lorimer (1991) found that sites were less likely to be disturbed in the few decades after disturbance, and others have observed that the probability of wind disturbance is affected by topography, subsurface water tables, and proximity to the Great Lakes.

Using the disturbance rate from Frelich and Lorimer (1991) in the equation developed by Runkle (1982), the age-class distribution shown in Table 4 was derived as follows.

> $(1\text{-}x)^{a} = y$, where “a” is an exponent to the function (1-x). The equation can be solved by using the converted equation, $a = \log y / \log (1\text{-}x)$, where:
>
> “x” is the annual average rate of disturbance as a proportion of the area, in this case .0057 to .0069 (Frelich and Lorimer 1991).
>
> “y” is the fraction of land area that would not have been affected by disturbance since before time “a”.
>
> “a” is the number of years since disturbance (and, presumably, the age of the forest for area “y”).

Table D-4. Time since disturbance, for the conservative and moderate estimates of average disturbance rates developed by Frelich and Lorimer (1991) used in the equation developed by Runkle (1982).

Percent of forested area undisturbed during at least the length of time shown in columns 2 and 3	Years since disturbance, for conservative (.0057) and moderate (.0063) estimates as a fraction of an area	
	0.057	**0.063**
1	806	665
5	524	433
10	403	333
20	282	232
30	211	174
40	160	132
50	121	100
60	89	74
70	62	52
80	39	32
90	18	15

This information shows that within the original hemlock-hardwood forest, probable estimates are that 50 percent of the area was older than 100-121 years, 30 percent of the area was older than 174-211 years, and 10 percent of the area was older than 333-403 years. A comparable study by Frelich (1995) estimated that 89 percent of the pre-European settlement northern hardwood forests in the Lake States were greater than 120 years old.

Fire Disturbance

Fire disturbance information for northern Wisconsin is not as well developed as for other parts of the Lake States. Because of this lack, information from Minnesota and Michigan is used, and estimated how it would have varied under Wisconsin's conditions.

Boreal forests are regulated by fire disturbance. This forest type is found on land units with relatively cold climatic regimes due to local topography and landscape juxtaposition. These land units often have water near the soil's surface due to impeded drainage or regional water tables (Curtis 1959). Fire return intervals are estimated at 50 years between stand-replacing fires (Lorimer 1989). Heinselman (1973), in the Boundary Waters Canoe Area, found 28-year average intervals between major fire occurrence years as determined by climatic conditions of prolonged subcontinental drought. The average annual area impacted was 0.8 percent of the study area (Heinselman 1981).

Pine forests are also regulated by fire. Jack pine forests are typically found on outwash plains and lake sand plains with droughty, sandy soils (Rudolph 1985). Whitney (1986) reported return intervals of 83-167 years for jack pine forests in Michigan, based on early survey records, which likely did not include small areas, or lighter burns. Simard and Blank (1982) determined that the fire interval for small areas within the Mack Lake area, Michigan, was 27 years during the time period prior to European settlement. At Itasca State Park, Minnesota, jack pine forests experienced fire at a return interval of about 22 years, with burn sizes varying from 580 acres to 31,960 acres (Frissell 1973).

Mixed pine forests had fire return intervals of 129-258 years, and oak-pine forests experienced stand-replacing fires at intervals of from 172-344 years, based on early survey records from two counties in northeastern Lower Michigan (Whitney 1986). These forests are associated with heads-of-outwash, some former dune/beach ridge features, and some overwashed moraines. In the Pictured Rocks National Lakeshore, Upper Michigan, surface fires impacted white pine-red pine forests on sandy soils on average each 22 years (Loope 1991). White pine-red pine-mixed hardwood forests in Itasca State Park, Minnesota, burned more frequently during warmer, drier climatic periods during the last 750 years (Clark 1990). Fires burned at about 9 year intervals during the 15th and 16th centuries and at about 13 year intervals in recent times.

In summary, fire disturbance occurred within boreal forests in the Lake States with return intervals of 28-50 years for stand-replacing fires, and surface fires occurred frequently. Jack pine forests in several locations within the Lake States had major fires at return intervals of 20-30 years. Surface fires were common in mixed pine and pine-hardwood forests, but stand-replacing fires occurred on the order of a few hundred years. Additional analyses will be needed to translate the disturbance frequency and extent into information on landscape patch structure and age-class distribution.

Many of the land units in northern Wisconsin are not clearly dominated by exclusively fire or wind disturbance, but are subject to a combination of both. This is partly because some areas are transition zones between fire and wind-disturbed systems. Also, some other areas exhibit finer-scaled patterns, as when narrow ridges rise above swamps and fire is more likely to impact the ridges. Disturbance regimes of these units also require further investigation.

Flood Disturbance

Flooding was the primary large-extent disturbance in aquatic and riparian ecosystems prior to European settlement. Flood disturbances provide a linkage between terrestrial

and aquatic ecosystems. Floods are known to affect food webs within aquatic ecosystems resulting in increase in populations of certain biota (Gregory et al. 1991; Bayley 1995), although the specific mechanisms of these ecosystems' functions are not well known in the Lake States. In general, it has been noted that:

- Aquatic life is adapted so that the vulnerable stages of life cycles occur during the periods of most stable flow within the yearly hydrologic cycle; and
- Leaf litter fall stimulates populations of decomposing organisms in the aquatic ecosystem. Timing of litterfall in relation to temperature and hydrograph conditions affects the rate of decomposition (IALE 1992).

Floods in northern Wisconsin are caused by rainfall or runoff from snowmelt. The size of a flood depends primarily on the amount of rainfall or snowmelt and the size of the watershed. Other characteristics such as soil type and water storage capacity also affect the response of individual watersheds. Watersheds with predominantly sandy soils absorb water and release it slowly. Thus, they produce much smaller floods than similar sized watersheds with clay or silt soils or large areas of saturated wetlands. Beaver are another important cause of flooding on the National Forests in Wisconsin. High beaver populations the past two decades have resulted in numerous beaver dams, which have inundated many miles of floodplain over the years.

Floods are described by their size and frequency. A common measure of flood size is the peak streamflow rate in cubic feet per second (cfs) or expressed as cubic feet per second per square mile (cfsm) when comparing watersheds of different size. Flood frequency is described by the recurrence interval or return period, which indicates the average number of years before a flood of the same size, is likely to occur again. Flood flows can be expected to range from 1.6 to 57.7 cfsm on the National Forests in Wisconsin for a wide range of recurrence intervals (CNF unpublished data).

Non-catastrophic floods on the Wisconsin National Forests are thought to occur every one to two years, forming and maintaining channels of rivers and streams. There has been no measurement of floods of greater magnitude, but there are records indicating that some have caused culvert, bridge, and road failures, and significant sedimentation to streams. Larger floods of 10 to 50 year recurrence intervals are infrequent by definition, but the Forest is sufficiently large that one or two floods of that magnitude occur each year.

The extent of a flood is determined by the width of the floodplain as well as the volume and rate of water flow. A sample of 119 stream reaches on the Forest has been classified according to the Rosgen system, and these are used to provide an estimate of the amount of floodprone area. The classification includes 'floodprone width', or distance from the channel that would typically be inundated by a relatively large and infrequent flood (i.e., recurrence intervals of 10 to 50 years).

Stream types (Rosgen Types) occurring on the Forest include streams with steep narrow channels and little floodplain (Type F); streams, which are somewhat less steeply sloping and have larger floodplains (Type B); and streams with low banks and broad floodplains (Types C and E; C types are wider and shallower than E types.) C and E types have the shallowest flood depths and lowest velocities, while F types have the deepest floods and greatest velocities. There are more than 2000 miles of stream on the Forest, based on estimates taken from topographic maps. Stream information is in the process of being converted to Geographic Information System layers, permitting analyses that will provide a more accurate estimate of actual stream miles.

Table D-5. Floodprone area calculations, based on estimated 2000 miles of stream on the Forests.

	Rosgen Type	Number[1] N	Number[1] %	Drainage Area (sq mi) Min	Drainage Area (sq mi) Mean	Drainage Area (sq mi) Max	Floodprone Width (ft) Min	Floodprone Width (ft) Mean	Floodprone Width (ft) Max[2]	Miles	Floodprone Acres
Upland	F	7	6	1.6	72.8	202.9	20	74	190	120	1,076
	B	11	9	0.8	56.5	220.5	10	74	162	180	1,615
	C	20	17	0.7	31.6	146.0	33	150	400	340	6,135
	E	8	7	0.6	4.2	11.0	13	163	300	140	5,091
Wetland	C	40	33	0.9	26.2	139.0	28	259	750	660	60,000
	E	33	28	0.3	4.7	13.4	36	305	1200	560	81,455
Total											155,372

1 Number of samples of stream type.
2 Estimate.

The CNNF has a total area of about 1,519,325 acres, of which the floodprone area is estimated to comprise at least 10 percent. There are relatively few acres subjected to deep floods with high velocities. The majority of flooded acres are in wetland areas where floodwaters are shallow and slow. The flood prone area is likely greater than 10 percent, because the estimate is based on 2,000 stream miles on the National Forests, and it is likely that there are more than 2,000 miles of stream. The estimate will be revised as more data becomes available.

Relative Impact of Different Natural Disturbances on the National Forests

Associating the probable dominant disturbance regime with forest types present at the time of the General Land Office survey in the late 1800s derived an estimate of the percent of National Forest area that was dominated by each type of disturbance. Table 6 presents the results of this analysis, conducted using the proclamation boundary for the National Forests and a GIS layer of Finley's (1976) map of historic forest types.

Table D-6. Estimate of probable dominant disturbance regimes and their extent of impact on National Forest lands, based on early European settlement era vegetation types as mapped by Finley (1976).

Forest types (Finley 1976)	% of forest	Estimated dominant disturbance regime: Wind	Fire	Flood	Combo
Hemlock/sugar maple	54	X			
Beech/hemlock	5	X			
Sugar maple / yellow birch	5	X			
Beech/sugar maple	<1	X			
Aspen/white birch	<1			X	
White spruce/balsam fir	<1			X	
Swamp conifers	21				X
White pine/red pine	6		X		
Jack pine/oak	4		X		
Oak openings	<1		X		
Brush	<1				X
Water	2				
Total by Category	100	65%	11%	10%*	14%

**10% estimate is taken from floodplain width analyses reported in Table D-6. The estimate is likely to increase when stream data is complete.*

Human Disturbance and Long-term Changes in the Range of Natural Variability

The study of past historical events, and their effects on the current structure and function of ecosystems is important for several reasons, as discussed by Christensen (1989). One important reason is the longevity of historical impacts. “For many years, ecologists assumed that the importance of the historical impacts of human interventions would diminish to insignificance given sufficient time for succession to “heal the wounds.” In recent years, however, this assumption has been seriously questioned. Many plants, especially forest trees, live a long time. Because of this longevity, past environmental conditions play a significant and continuing role in the structure of most forest ecosystems.” (Christensen 1989).

Changes in Natural Disturbance Regimes

Fire

Disturbance regimes of fire, wind, and water have been altered by human influences. Attempts have been made to suppress fires because of risks to human safety and property. In the most flammable landscapes, return intervals for catastrophic fires may not have been reduced by fire suppression techniques. At Mack Lake in lower Michigan, return intervals for fires of greater than 10,000 acres during pre-European times averaged 35 years; fires of this size have occurred on an average of every 25-27 years during recorded history (Simard and Blank 1982). Reductions in the frequency, extent, and variability of ground fires have almost certainly occurred as a result of fuel removal, firebreak construction, and other fire suppression activities. Reductions in fire frequency have been shown to change dominant successional pathways (Frelich and Reich 1995), and are likely responsible for additional changes in the forest understory and midstory. For example, it is known that certain native herbaceous and shrub species become invasive in the absence of fire disturbance, and displace other components of plant communities.

Wind

Wind disturbance has been shown to affect younger northern hardwood forests differently than older forests. Dahir and Lorimer (1996) found that while canopy gaps were more numerous in pole (40 yr old) and mature (100-175 yr old) stands, they were less than one-fourth as large, more homogenous in size distribution, and occupied only half the total area as compared with gaps in old-growth forests. Tyrrell and Crow (1994) found that in hemlock-hardwood forests ranging in age from 177 to 374, the total area and average size of canopy gaps increased with stand age. Frelich and Lorimer (1991), in their study of old-growth hemlock-hardwood forests, found that wind disturbance was less likely to recur within the first few decades after a previous wind disturbance. Lorimer (1989) summarized earlier studies of the temperate hardwoods, which indicated that older forests generally had higher rates of gap formation, larger average gap sizes, and gaps that were not quickly closed over by border trees. This evidence leads us to conclude that the second-growth hardwood forests of northern Wisconsin are likely to have smaller windthrow gaps, a narrower range of gap sizes, and less total gap area than existed in the primary forests. This change in landscape structure has effects on forest succession: different tree species have been shown to gain a competitive advantage in gaps of different sizes and orientations. Smaller gaps were shown to have lower woody species diversity, fewer stems, and slower growth (Runkle 1982).

Flooding

Within the U.S., flood prone areas are estimated at 6 percent, of which only 2 percent are thought to be in "some semblance of a natural riparian ecosystem" (Hunter 1990:146). What proportion of the Chequamegon-Nicolet's flood prone areas are functioning as natural systems is unknown, as flooding in current times has been reduced by a combination of stream channel downcutting and changes in bank structure that occurred during early logging, effects of dams and other water control structures, and reductions and relocations of beaver populations as compared with historical levels. We expect that reductions in flooding have had effects on food webs both in streams and riparian zones, although the specifics are not presently known. Despite these unknowns, it is apparent that riparian areas represent a significant ecological feature that is scarce nationally and at least slightly more abundant on these National Forests.

Dams can have negative effects on aquatic species. The reservoirs created by dams "tend to be occupied by common and widespread species", and "tend to replace much more diverse habitats, including waterfalls, rapids, and floodplain wetlands, leading to the loss of the numerous species of plants and animals specific to running waters." Loss of habitat and obstruction to dispersal can cause aquatic species distributions to become fragmented and less viable and sometimes lead to extirpation. Structural changes other than dams, such as channelizing, can also lead to problems for biota. (UNEP 1995:754-755)

Activities in addition to damming have affected hydrography, water quality, and aquatic communities. Beaver once occupied the role of a keystone species in the Lake States, providing an important control on flood disturbance, and changing the size and nature of flood events. Beaver were also responsible for initiating vegetative succession in riparian zones and adjacent forests. They may have provided patches where aspen was perpetuated within the hardwood forests, and these patches may have provided the seed source that allowed aspen to become spatially dominant after early logging and burning. The reduction of beaver populations has changed the aquatic systems as well as the adjacent riparian and terrestrial systems (Strong 1997).

Changes in land use have been shown to affect hydrography of streams. On open lands, snowmelt occurs at 2-3 times the rate of snowmelt in forests over 15 years of age. When too much of the basin is in open land (more than about 60% of the stream's basin area), rapid snowmelt increases streamflow rates by up to three times of that in mixed land-use areas, resulting in increased channel erosion and sedimentation, and downstream transport of organic material that could have been processed to sustain the food web (Verry 1992).

Dead woody material in the streams once provided a buffer against strong currents, provided habitat for fish, invertebrates, and microorganisms, and captured instream detritus that stimulated the food web. "Nearly all rivers, streams, and brooks in eastern North America have been cleaned for the purpose of transporting barges, logs, and steamboats. River cleaning consisted of cutting streamside trees, removing rocks and dead trees from the channel and digging new channels to cut off oxbows... stream channels are now straighter, shallower, and warmer." (Verry 1992). These simplified aquatic habitats have less energy available to support aquatic communities, which results in reduced biological diversity.

Large woody material as well as deciduous leaf litter is needed. "Both forest litter and dead trees play a significant role in the structure and function of stream ecosystems... "Deciduous trees provide a large amount of leaf litter and shade to forest streams; however, the pioneer species of aspen and birch that dominate the Lake States do not

provide stable large woody debris in stream channels. Large conifers provide the best source of large woody debris for habitat structure in the stream channel because their size increases water depth by damming and pool scouring, and because they are more resistant to decay... A mixture of deciduous and conifer species provide both food, stream structure and sunlight openings to increase primary production in the stream channels." (Verry 1992).

In summary, natural disturbances and keystone species have been reduced in aquatic and riparian systems. The physical condition of the streams has been affected by early logging: woody material is lacking, stream channels are downcut, sediment that comprises stream bottoms is of a different quality, and banks have been scoured and denuded of woody vegetation. Streams and rivers have not yet recovered from this historic damage. In more recent times, the introduction of exotic species, over-harvesting, ongoing stream clearing (albeit at a lesser extent than during early logging), removal of some streamside vegetation, continued damming, and pollution have together led to the extirpation of some native species and undoubtedly impacted other parts of food webs. Recreational use and road construction has resulted in localized erosion and sedimentation. All of these impacts have changed the aquatic and riparian systems. In many regards, these systems are in poor condition, well outside the range of natural variability.

Changes in Forest Composition and Age Structure

Consequences of clearcutting, slash burning, and stream and river modifications during the early logging era, together with repeated cycles of cutting and the suppression of natural disturbances since that time, may have resulted in long-term changes in the ecosystems of northern Wisconsin that place them outside the range of natural variability. Whitney (1987) has summarized these changes for the forests of Michigan, and many of his observations are also true of Wisconsin forests; "Where the human-imposed disturbance regimes approximated pre-settlement conditions, i.e. in the fire-adapted jack pine type and in the swamp conifers, the change has been minimal." However, "in other cases, the disparity between the primeval and the secondary forest is much more obvious... hemlock and white pine were considerably more important... [and] are only slowly, if at all, regaining their former position." "The transition from the mixed pine type to the aspen and oak types reflects the human imposition of a new disturbance regime to which many of the larger pines were not adapted." Aspen was "a minor and temporary constituent of windthrows and other disturbed sites in the pre-settlement forest ... due to its relatively shade-intolerant nature" (Whitney 1987). Frelich and Lorimer (1991), summarizing other work, stated that "trees of all pioneer species typically made up less than or equal to 5 percent of the pre-settlement northern hardwood forest". The aspen-birch forest type currently occupies a large percentage of the landscape, comprising about 30 percent of forested lands in northern Wisconsin according to Forest Inventory and Analysis (FIA) measurements made in 1996.

Early-successional species that are tolerant of human disturbances have come to dominate the current landscape, and this condition is to some degree self-perpetuating. These species typically have excellent dispersal capabilities, and as they increase in abundance, their seed pools become so large that they are capable of colonizing any suitable sites that become available, including ones that formerly would have been colonized by different species. Thus, early-successional species are able to saturate habitats and force out other, less disturbance-adapted species. Effects of this landscape saturation may persist even if the disturbance regime is changed back to one of lesser

human impact. The accumulated effects of changes in disturbance patterns and species composition in the post-settlement era "are having profound and lasting effects on many species and their ecological relationships." (Alverson et al. 1994).

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