Range of Natural Variability in Forest Structure for the Northern Superior Uplands

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September 13, 1999
Final revised version

INTRODUCTION

The purpose of this report is to elucidate the landscape age structure of different forest types (or ecosystem types) in the Northern Superior Uplands Section of northeastern Minnesota under the natural disturbance regime in effect during presettlement times (1600-1900). To do this, I provide a successional pathway among several vegetational growth stages (VGS) for each forest type, and then show a reasonable range of the proportion of the landscape in each VGS given the historic disturbance regime for that forest type. VGS are combined successional and developmental stages that occur after disturbance, where successional stage refers to changes in species composition over time, and developmental stage refers to stand structure over time. For example, a post-fire birch forest may succeed to white pine and then to balsam fir. At the same time it may go from young even aged sapling or pole stands, to mature stands, to multi-aged stands. The VGS interrelates these two schemes so that we have sapling/pole birch mature birch with pine understory mature pine multi-aged pine with fir understory multi-aged fir.

Simulating the effects of natural disturbance on landscape age distribution

A typical box and arrow type of simulation run on a 1-year time step is adequate for this purpose:

1. Each vegetation growth stage is represented by one box, which holds information on the proportion of all vegetation within one ecosystem type is within that vegetation growth stage

2. Devise a transition matrix for annual transfers among the vegetation growth stages, as indicated by research on rotation periods and succession. The transition matrix specifies that:

> 2A. A fraction of the value in the box will be transferred to the next higher vegetation growth stage, on an annual basis, according to this formula: 1/x, where x is the number of years a stand would spend in that vegetation growth stage in the absence of stand-killing disturbance.
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> 2B. A fraction of the value in each box will be transferred to the first (or post stand-killing disturbance) vegetation growth stage, on an annual basis, according to this formula: 1/y, where y is the length of the rotation period for stand-killing

disturbance. Be careful: this assumes a constant hazard function for the duration that each stand is in a given vegetation growth stage. Adjustments to account for non-constant hazard can be made by changing the fraction disturbed annually in successive growth stages.

2C. If there is more than one type of stand-killing disturbance, then step 2B will be repeated using the appropriate rotation period for each additional disturbance type. Note that the transfer may not always be to the same box for each disturbance type. There may need to be two or more post stand-killing disturbance boxes. For example, as explained in Chapter 4, a stand of a shade-tolerant, late-successional species, such as balsam fir, may blow down in a heavy windstorm, but still remain balsam fir, even though now dominated by small seedlings of fir. If the same fir stand burned, fir may be removed, and it may succeed to aspen. In a case such as this, there would be a post stand-killing disturbance vegetation growth stage called something like 'seedling balsam fir' for post-wind stands, and one called something like 'seedling aspen' for post-fire stands.

2D. If there are partial disturbances (non stand-killing disturbances) that affect vegetation growth stage, these can be included also, as long as the rotation period for them is known. Surface fires, for example, may leave the forest overstory intact in pine forests, but cause the stand to remain in mature pine, rather than succeed to a more shade-tolerant species.

3. The simulation can be run assuming an equal acreage or proportion of stands in each vegetation growth stage at the start, and then run long enough to come to equilibrium. This usually means running for at least one rotation period for the dominant disturbance type.

4. Repeat the whole exercise (steps 1-6) for each ecosystem type on the landscape, and then sum the results to see what the whole landscape would look like under a given disturbance regime.

Preparing for the simulation

A unique web of different vegetation growth stages, with many different types of transfers among boxes may develop for each ecosystem type. It is up to the investigator in each case to have a thorough understanding of the stand development and successional relationships to disturbance for all disturbance types that may occur in the ecosystem, in order to properly structure the simulation. A three-step process is necessary to work out the web of growth stages and get ready to run the simulation.

Preparation Step 1. Vegetation growth stages must be quantitatively related to age classes after disturbances of all types that will appear in the simulation (necessary to get the variable x in simulation step 2A above). This may not be accurate for all individual stands, but all we need here are the average ages at which stands switch from one vegetation growth stage to another. This can often be done with size/age class data from field plots, or even from forest inventory data.

Preparation Step 2. Relate the vegetation growth stages to each other with a set of ‘successional rules’.

Preparation Step 3. Estimate rotation periods for the ecosystem and time period of interest (necessary to get the variable y in simulation step 2B above). Many managers of reserves in North America today are interested in the so-called pre-European settlement disturbance regime (usually the historical period 1600-1900) since their goal is to compare the current forest with what is thought to be natural.

Preparation Step 4. Decide on the most appropriate model for the theoretical age distribution (i.e. hazard function) for each ecosystem type and disturbance type.

I caution the reader that even the estimates of proportion of stands across the landscape using the bounds of the confidence limits for the rotation period still assume an infinitely large landscape. Because disturbances can be large (fires burning 100,000 ha are common, and a downburst family may affect an equally large area), variation in the proportion of the landscape in a given vegetation growth stage will essentially be zero to 100% for small landscapes in one patch. If the landscape is a mosaic of ecosystem types, and each ecosystem type has many widely scattered occurrences, then the proportion in each vegetation growth stage for each ecosystem type may be quite stable.

RESULTS

Ecosystem types

Land Surveyor records and a recent classification of plant communities by Kurt Rusterholz (MN DNR) indicate the presettlement landscape of the Northern Superior Uplands comprises eight major ecosystem types:

Mesic hardwood ecosystem dominated by sugar maple

Mesic conifer ecosystem with white and red pine stands (mainly north shore)

Dry-mesic conifer ecosystem with red and white pine (mainly BWCAW)

Lowland conifer ecosystem dominated by black spruce

Rich swamp ecosystem with white cedar and black ash

Near-boreal mesic ecosystem with paper birch, aspen, black spruce and balsam fir

Near-boreal dry forests of jack pine and black spruce

Near-boreal dry forests of jack pine, aspen, pin oak and bur oak

Rotation periods

The three forest types have the following set up as described under ‘preparing for the simulation’ above. For fire rotation periods in each ecosystem type, I determined the ‘best estimate’ from the literature, and with consultation from other members of the natural range of variability working group, and then made that the center of lower and upper bounds with a two-fold difference (Table 1). Theoretical age distributions were negative exponential for stand-killing fire and combination of uniform and negative exponential with waiting period of 40-50 years for stand-leveling wind in all cases. Note that disturbance regimes for sugar maple forests, jack pine-black spruce, jack pine oak, and white and red pine forests are relatively well understood, with a number of major studies in the literature. The brackets for these forests are highly likely to encompass the actual range of variability that occurred in the historic 1600-1900 period. Moderately well understood are the lowland conifer forests of black spruce and the mesic spruce-fir-birch types. Heinselman presents some data on these types in his papers. Finally, the rich swamp forests are not well understood. The rotation period and successional pathways presented here are the result of expert opinion by myself and the natural variability working group.

Table 1. Rotation periods used in the simulations. Stand-killing fire rotation data from Swain 1973, Heinselman 1973, 1981, Frelich 1992, Johnson 1992). Surface fire data from Frissell 1973, Heinselman 1973, 1981. Stand-leveling wind data from Canham and Loucks 1984, Whitney 1986, Frelich and Lorimer 1991. Partial wind data from Frelich and Lorimer 1991.

Ecosystem	Rotation period brackets		
	Stand-leveling wind	Stand-killing fire	Surface fire
Sugar maple	1000-2000	2000-4000	
Mesic and dry-mesic white and red pine	1000-2000	150-300	40
Lowland conifer	1000-2000	150-300	
Rich swamp	1000-2000	500-1000	
Mesic birch-aspen-spruce-fir	1000-2000	100-200	
Jack pine-black spruce-oak	1000-2000	50-100	

Successional rules and simulation results

The following sets of successional rules were used to set up the successional web, along with its transition probabilities from one vegetation growth stage to another for each disturbance type. All of the stand ages, developmental stages and successional stages are based on synthesis of data from Frelich 1992, Frelich and Lorimer 1991, Frelich and Reich 1995, Groot and Horton 1994, Heinselman 1961, 1963, 1970, 1973, 1981, and West wood Professional Services, Inc, 1998. All of this material will also be synthesized in Frelich, in Press.

Ecosystem I. Sugar maple

Vegetation growth stages and successional rules:

1. Sapling stands of birch 0 to 10 years after severe fire in any VGS

2. Pole-mature stands of birch 11 to 50 years after severe fire in any VGS, or after

windthrow in this VGS or VGS 1

3. Mature stands of birch with maple understory 51-100 years after severe fire in any VGS

4. Mature stands of maple 101-150 years after severe fire in any VGS

5. Multi-aged stands of maple 151 years after fire in any VGS, or 121 years after windthrow in VGS 3, 4 or 5

6. Sapling stands of maple 0 to 10 years after windthrow in VGS 3, 4, or 5

7. Pole-mature stands of maple 11-120 years after windthrow

Table 2. Estimated range of variability for sugar maple forest

Vegetation growth stage	Age	% of landscape
Sapling birch	0-10	0.2-0.5
Pole-mature birch	11-50	1.0-1.9

Mature birch-maple	51-100	1.0-1.8
Mature maple	101-150	1.2-2.2
Multi-aged maple	151	83.5-91.2
Sapling maple	0-10	0.5-0.9
Pole-mature maple	11-120	5.0-9.1

Ecosystem II. Mesic white and red pine

Vegetation growth stages and successional rules:

1. Sapling stands of birch 0 to 10 years after severe fire in any VGS

2. Pole-mature stands of birch 11 to 50 years after severe fire in any VGS

3. Mature stands of birch with white pine understory, 51-80 years after severe fire in any VGS

4. Mature stands of white pine 81-120 years after severe fire in any VGS or 51 years after wind in VGS 3 or 4

5. Multi-aged stand of white pine, spruce-fir 121-200 years after severe fire in any VGS or after lack of surface fire in VGS 9

6. Multi-aged spruce and fir 201 years after fire

7. Sapling-pole pine for 0-50 years after wind in VGS 3 or 4

8. Sapling-pole spruce-fir 0-50 years after wind in VGS 5

9. Multi-aged white pine after surface fire in VGS 5

Table 3. Estimated range of variability for mesic white and red pine

Vegetation growth stage	Age	% landscape
Sapling birch	0-10	3.2-6.3
Pole-mature birch	11-50	11.3-19.8
Mature birch-pine	51-80	9.7-12.2
Mature white pine	81-120	9.2-13.1
Multi-aged pine-spruce-fir	121-200	11.8-12.4
Multi-aged spruce-fir	201	23.5-44.3
Sapling-pole pine	0-50	0.6-1.3
Sapling-pole spruce-fir	0-50	1.2-1.4
Multi-aged white pine	121	9.9-10.7

Ecosystem III. Dry-mesic red and white pine (new page 7--table rerun February 22, 2000, after finding error in coefficient for pole-mature birch)

Vegetation growth stages and successional rules:

1. Sapling stands of birch 0 to 10 years after severe fire in any VGS

2. Pole-mature stands of birch 11 to 50 years after severe fire in any VGS

3. Mature stands of birch with white pine understory, 51-100 years after severe fire in any VGS

4. Mature stands of red and white pine 101-140 years after severe fire in any VGS, or 51 years after wind in VGS 3 or 4

5. Multi-aged stand of red and white pine, spruce-fir 141-200 years after severe fire in any VGS or after lack of surface fire in VGS 9

6. Multi-aged spruce and fir 201 years after fire

7. Sapling-pole pine for 0-50 years after wind in VGS 3 or 4

8. Sapling-pole spruce-fir after 0-50years after wind in VGS 5

9. Multi-aged white pine after surface fire in VGS 5

Table 4. Estimated range of variability for dry-mesic red and white pine

Vegetation growth stage	Age	% landscape
Sapling birch	0-10	3.2-6.3
Pole-mature birch	11-50	11.3-19.9
Mature birch-pine	51-100	11.9-17.9
Mature pine	101-140	8.7-11.8
Multi-aged pine-spruce-fir	141-200	9.1-9.6
Multi-aged spruce-fir	201	24.0-45.9
Sapling-pole pine	0-50	0.6-1.4
Sapling-pole spruce-fir	0-50	1.2-1.3
Multi-aged white pine	121	7.7-8.1

Ecosystem IV. Lowland conifer

Vegetation growth stages and successional rules:

1. Seedling black spruce 1-40 years after fire or wind

2. Sapling-pole black spruce 41-80 years after fire or wind

3. Pole-mature black spruce 81-160 years after fire or wind

4. Multi-aged black spruce 161 years after fire or wind

Table 5. Estimated range of variability for lowland black spruce

Vegetation growth stage	Age	% landscape
Seedling black spruce	1-40	18-32
Sapling-pole black spruce	41-80	15-23
Pole-mature black spruce	81-160	21-23
Multi-aged black spruce	161	22-46

Ecosystem V. Rich swamp

Vegetation growth stages and successional rules:

1. Seedling-sapling ash-birch-cedar 1-20 years after wind or fire

2. Sapling-pole ash-birch-cedar 21-50 years after wind or fire

3. Pole-mature ash-birch-cedar 51-100 years after wind or fire

4. Multi-aged ash or cedar 101 years after wind or fire

Table 6. Estimated range of variability for rich swamp forest

Vegetation growth stage	Age	% landscape
Seedling-sapling	1-20	2.9-5.7
Sapling-pole	21-50	0.4-0.9
Pole-mature	51-100	6.8-12.2
Multi-aged ash or cedar	101	81.3-89.9

Ecosystem VI. Mesic birch-aspen-spruce-fir

Vegetation growth stages and successional rules:

1. Sapling stands of birch and aspen 0 to 10 years after fire in any VGS

2. Pole-mature stands of birch-aspen 11 to 50 years after fire in any VGS

3. Mature stands of birch aspen with conifer understory, 51-80 years after fire in any VGS

4. Multi-aged stands of conifers 81 years after fire in any VGS, or 81 years after wind in VGS 3,4,5 or 6.

5. Sapling-pole stands of conifer 0-50 years after wind in VGS 3, 4 or 6

6. Pole-mature stands of conifer 51-80 years after wind in VGS 4

Table 7. Estimated range of variability for mesic birch, aspen, spruce, fir

Vegetation growth stage	Age	% landscape
Sapling birch	0-10	4.8-9.2
Pole-mature birch	11-50	15.9-26.1
Mature birch-conifer	51-80	10.3-14.9
Multi-aged conifer	81	46.8-66.6
Sapling-pole conifer	0-50	1.6-2.1
Pole-mature conifer	51-80	0.1-0.8

Ecosystem VII. Jack pine-black spruce

Vegetation growth stages and successional rules:

1. Seedling jack pine 1-10 years after fire

2. Sapling jack pine 11-20 years after fire

3. Pole jack pine 21-50 years after fire

4. Mature jack pine 51-70 years after fire

5. Large jack pine 71-110 years after fire

6. Jack pine-fir-spruce 111-180 years after fire

7. Multi-aged fir-spruce-cedar 181 years after fire or 81 years after wind

8. Seedling fir-spruce-cedar 1-30 years after wind in VGS 6 or 7

9. Sapling fir-spruce-cedar 31-50 years after wind in VGS 6 or 7

10. Pole/mature fir-spruce-cedar 51-80 years after wind in VGS 6 or 7

Table 8. Estimated range of variability for dry jack pine black spruce

Vegetation growth stage	Age	% landscape
Seedling jack pine	1-10	9.2-17.1
Sapling jack pine	11-20	8.4-14.2
Pole jack pine	21-50	19.4-26.5
Mature jack pine	51-70	10.6-12.2
Large jack pine	71-110	13.2-14.9
Jack pine-fir-spruce	111-180	9.2-14.9
Multi-aged fir-spruce-cedar	181	6.5-21.3
Seedling fir-spruce-cedar	1-30	0.6-0.6
Sapling fir-spruce-cedar	31-50	0.3-0.3
Pole/mature fir-spruce-cedar	51-80	0.2-0.4

Ecosystem VIII. Jack pine-aspen-oak

Vegetation growth stages and successional rules:

1. Seedling jack pine-oak-aspen 1-10 years after fire

2. Sapling jack pine-oak-aspen 11-20 years after fire

3. Pole jack pine-oak-aspen 21-50 years after fire

4. Mature jack pine-oak-aspen 51-70 years after fire

5. Large jack pine-oak-aspen 71-110 years after fire

6. Multi-aged fir-spruce-oak 110 years after fire or 81 years after wind

7. Sapling fir-spruce-oak 1-30 years after wind in VGS 6

8. Pole fir-spruce-oak 31-50 years after wind in VGS 6

9. Pole/mature fir-spruce-oak 51-80 years after wind in VGS 6

Table 9. Estimated range of variability for dry jack pine, aspen, oak.

Vegetation growth stage	Age	% landscape
Seedling pine-oak-aspen	1-10	9.2-17.1
Sapling pine-oak-aspen	11-20	8.4-14.2
Pole pine-oak-aspen	21-50	19.4-26.5
Mature pine-oak-aspen	51-70	10.6-12.2
Large pine-oak-aspen	71-110	13.2-14.9
Multi-aged fir-spruce-oak	110	9.7-27.7

Sapling fir-spruce-oak	1-30	0.6-0.6
Pole fir-spruce-oak	31-50	0.3-0.3
Pole/mature fir-spruce-oak	51-80	6.2-8.9

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