Photo: Paul Jost

Forest blowdowns and relative susceptibility of northern hardwood and southern boreal tree species

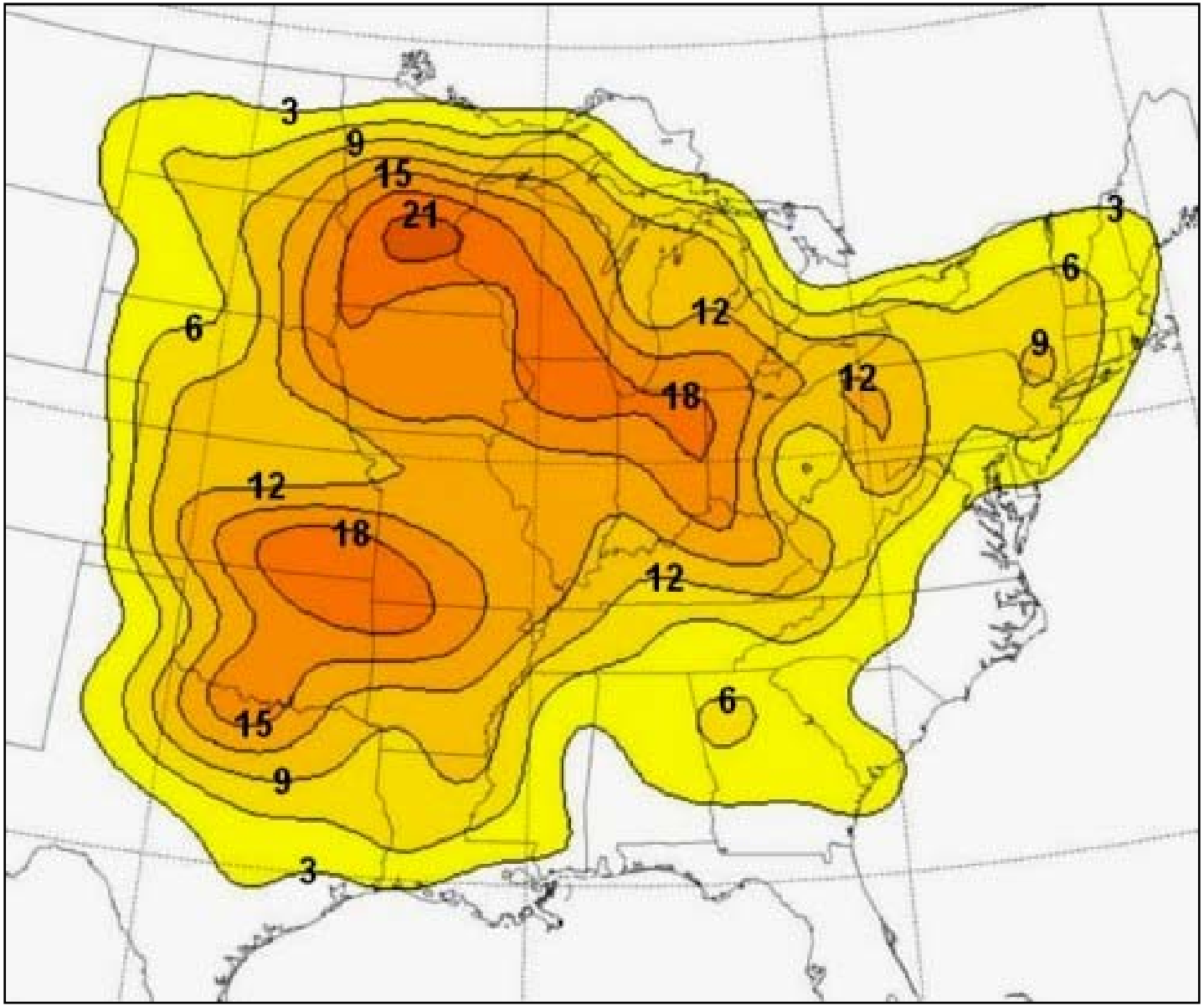
Lee E. Frelich—Director, University of Minnesota Center for Hardwood Ecology

Dave Hansen, University of MN
Agricultural Experiment Station

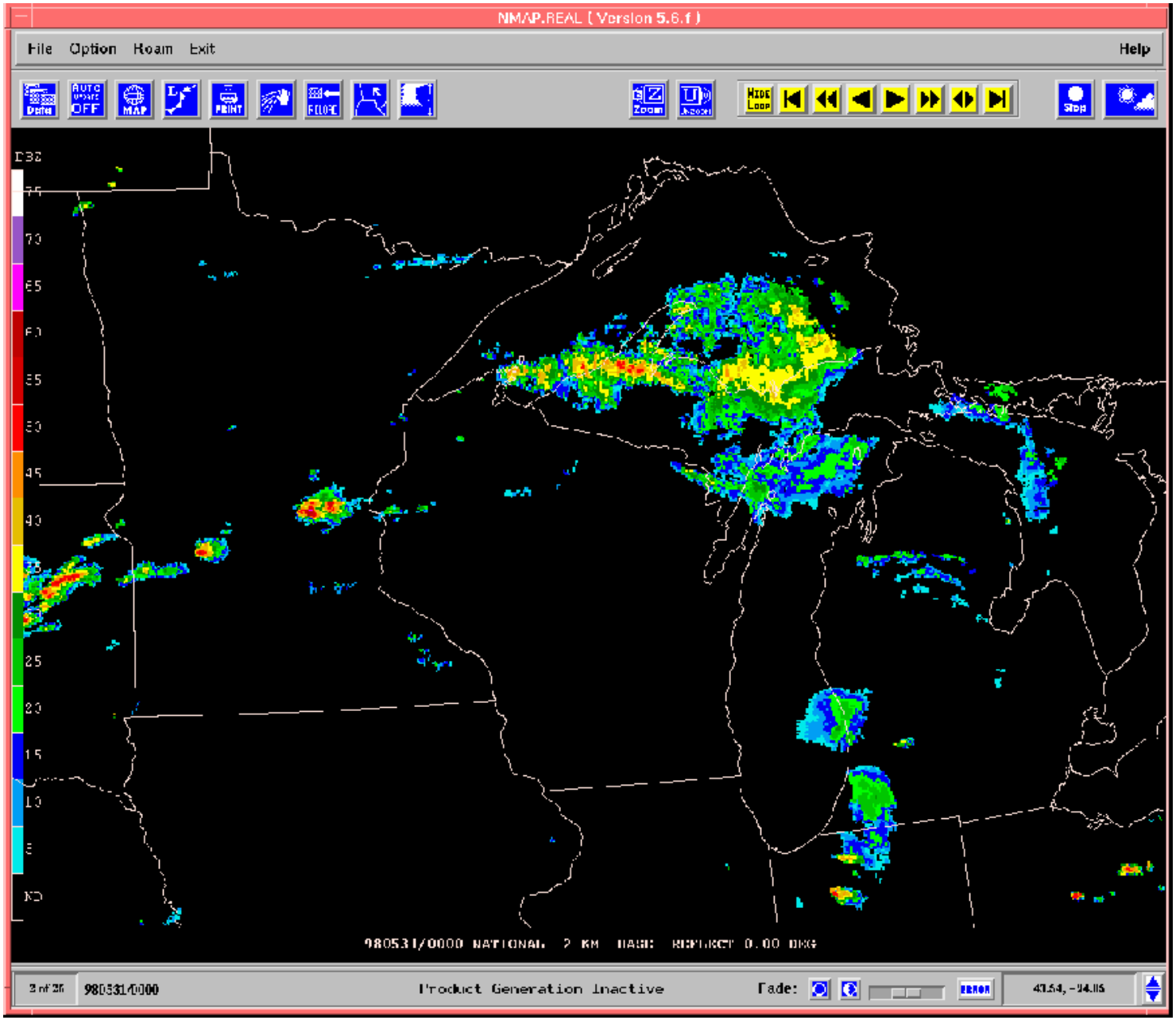
Mammatus clouds in an approaching Midwestern severe thunderstorm—a sign of downburst or tornado activity

From COMET, 1999, modified from Weisman, 1993.

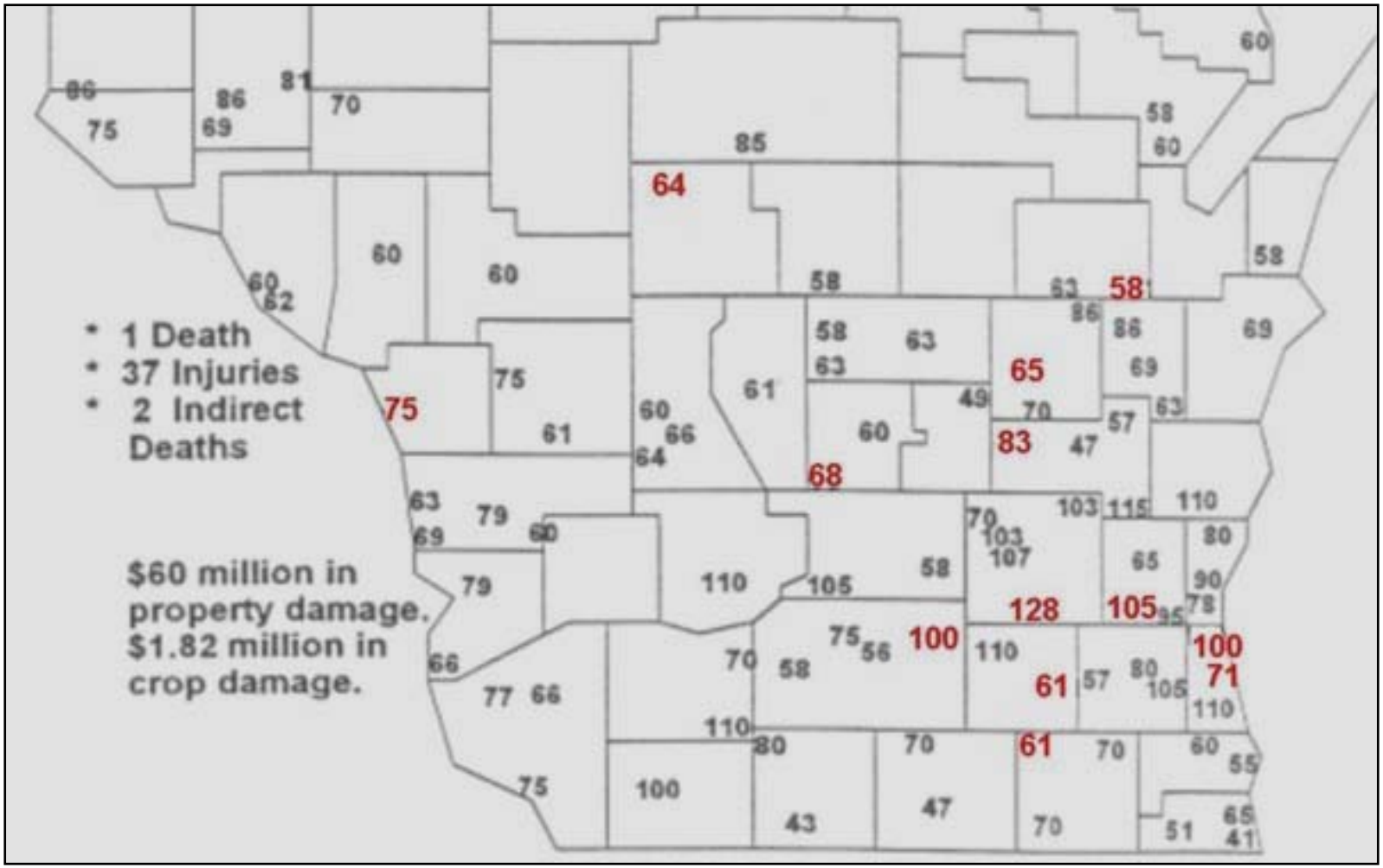
Derecho downburst development



From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

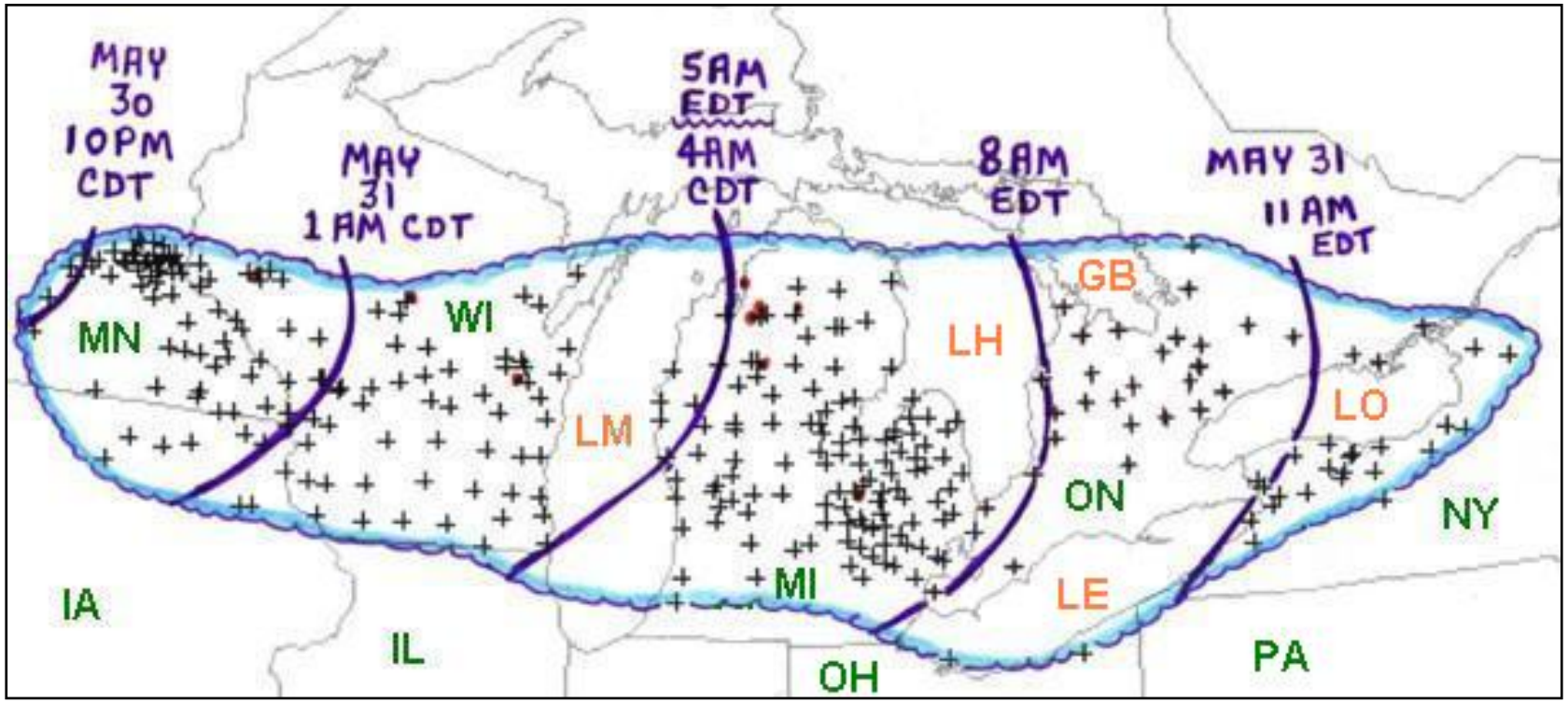


From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos



Maximum wind gusts from May 30-31, 1998 derecho in WI

From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos



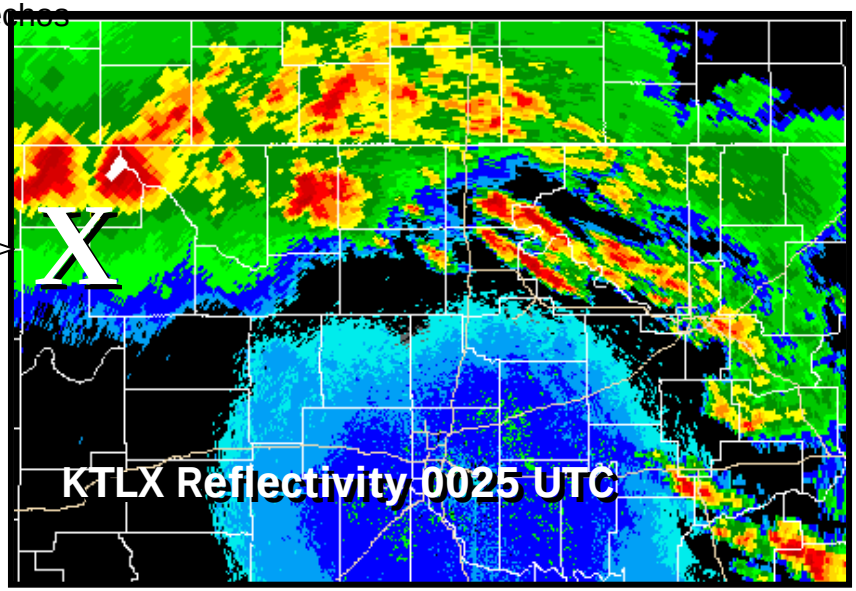
May 30-31, 1998 Bow echo derecho (6 dead, 190 injured, $291,000,000 damage).

From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

Supecell derecho

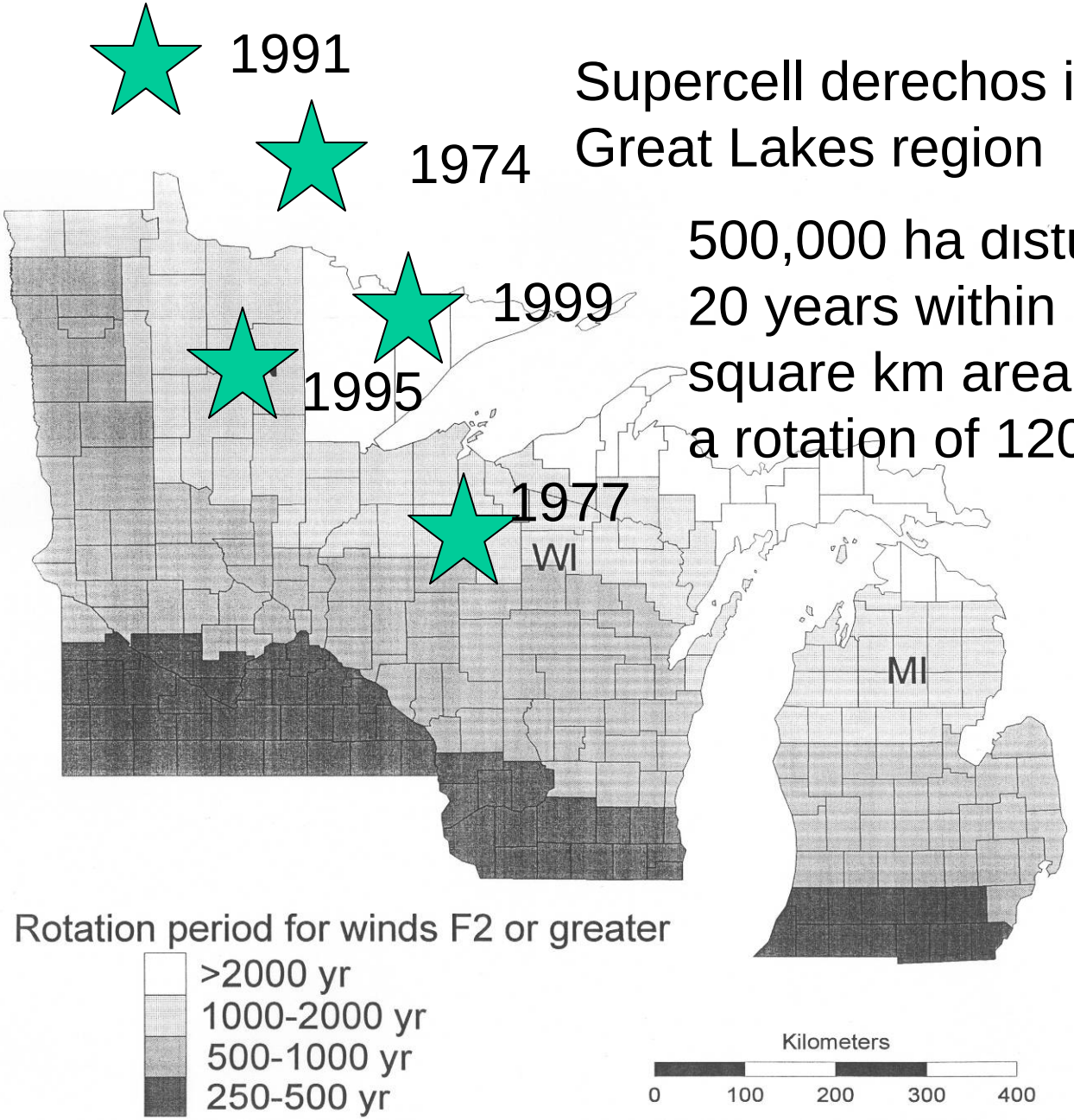
From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

Photo taken here



Supercell derechos in the western Great Lakes region

500,000 ha disturbed in 20 years within a 300,000 square km area suggests a rotation of 1200 years



Differences between supercell and non-supercell derechos:

1. Supercell derechos:

- High wind lasts 20 minutes or more
- Little is known about how rotation interacts with downburst
- Have extremely high precipitation rates and sometimes large hail
- Have a zone of intense devastation about 40 miles long with sharp boundaries

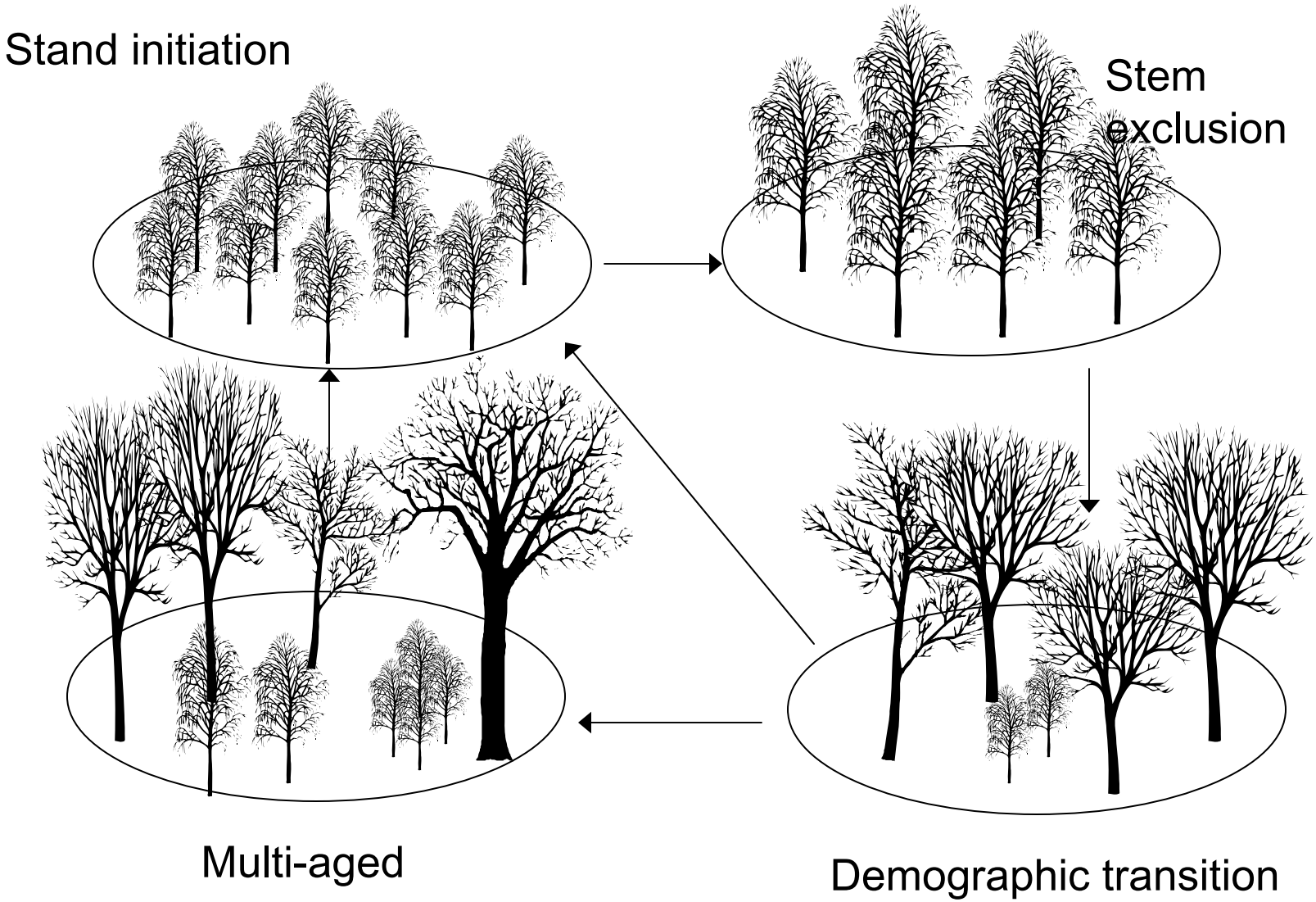
2. Bow echo derechos:

- Last 5 minutes
- Have 0.5-1 inch of rainfall
- Cover large areas with scattered relatively small patches of intense devastation

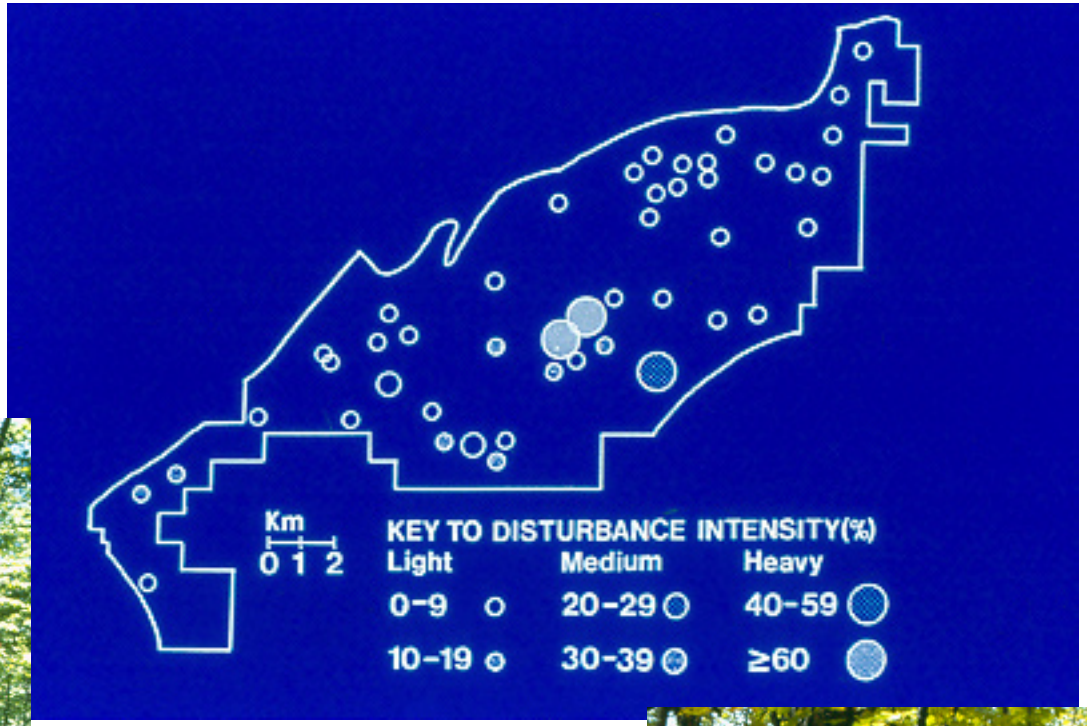
Sugar maple-hemlock wind dominated regime, with rare severe fires and succession to white pine

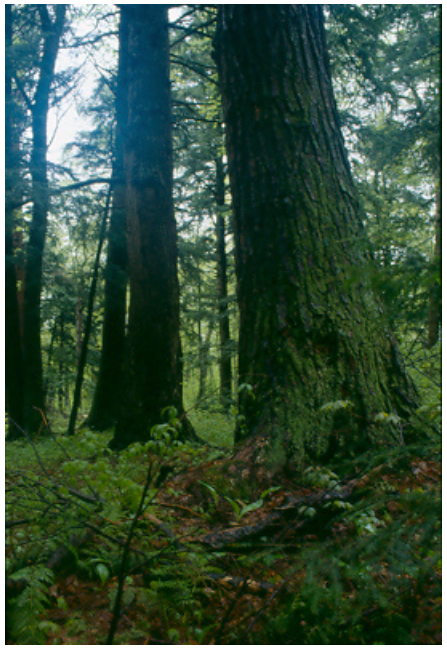
Lee Frelich

The Porcupine Mountains Wilderness State Park has 35,000 acres of unlogged sugar maple-hemlock forest, where a landscape-scale analysis of wind dynamics was completed



Stand development (Frelich 2002)


Km
0 1 2
KEY TO DISTURBANCE INTENSITY(%)
Light
Medium
Heavy
0-9
10-19
20-29
30-39
40-59
≥60

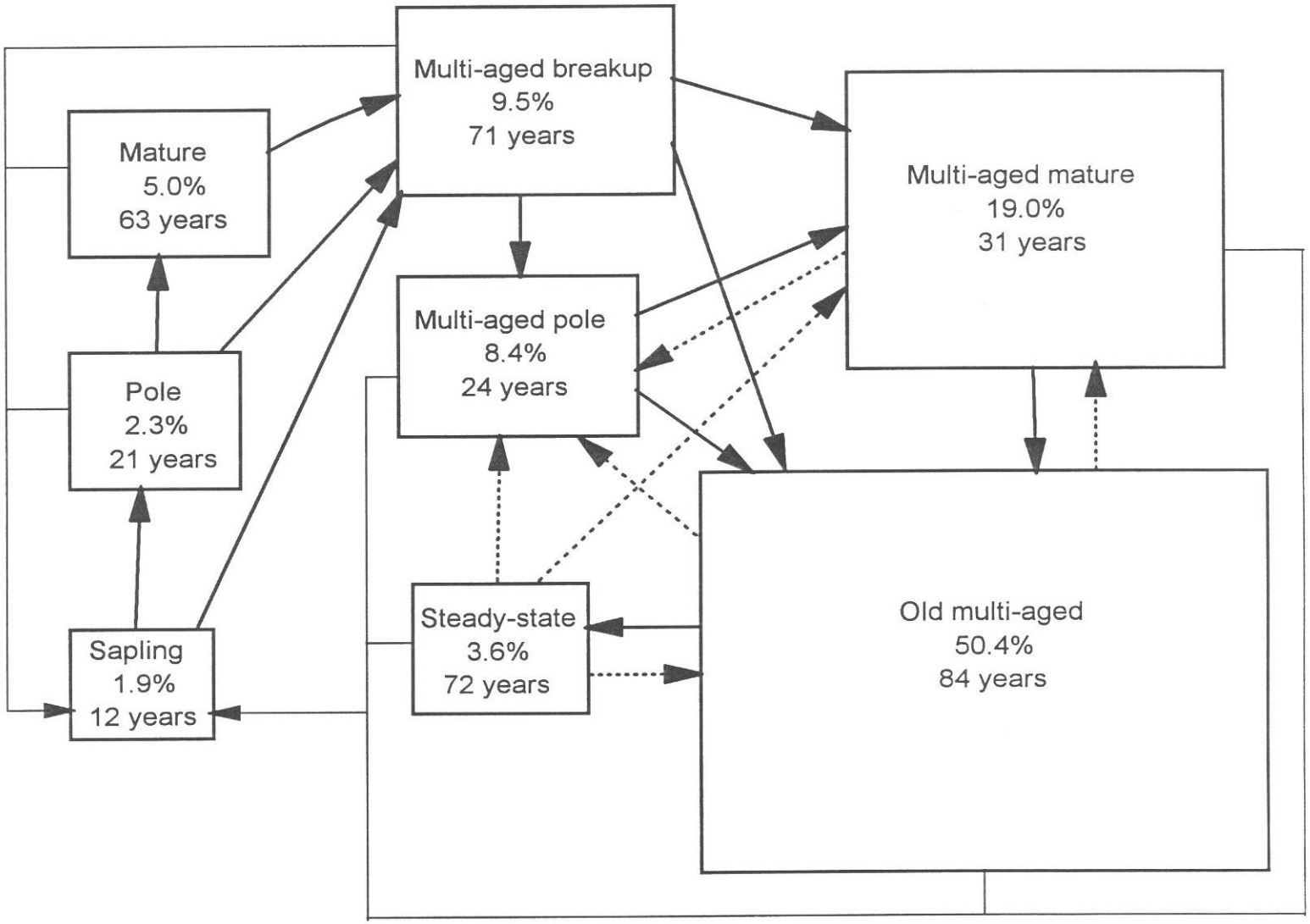


High wind

Fire

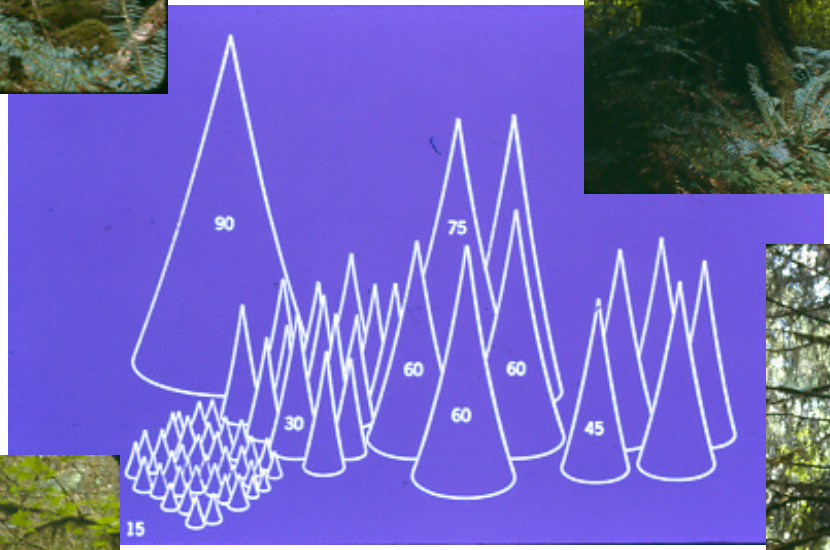
Low wind

Most disturbance is not stand leveling—the frequency of partial Disturbance and gap formation is an order of magnitude higher



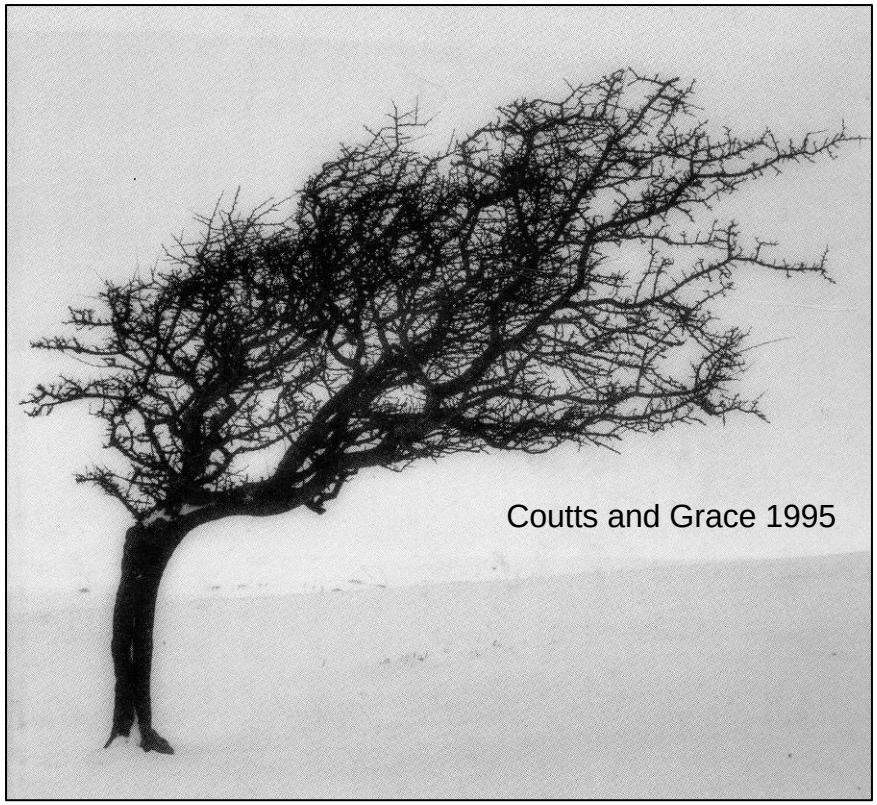
From Frelich 2002, Forest dynamics and disturbance regimes
Cambridge University Press

Multi-aged stand—Sitka spruce, Hoh River Rainforest, WA



Adaptive Growth Hypothesis:

Living materials grow with respect to the stresses that occur. Growth patterns seek to have uniform stress distribution across surface.



What types of disturbance would this protect against?

Where would you expect to see this?

What is the timescale of this response to environmental change?

Examples

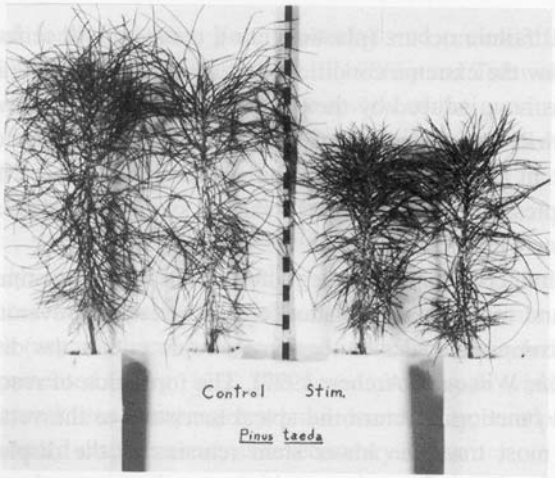


Fig. 14.4. Six-month-old seedlings of *Pinus taeda*. L. exhibiting reduced height and shorter leaf and needle growth in response to mechanical stimulation induced as flexing (Stim.). Each division on the scale represents 10 mm.

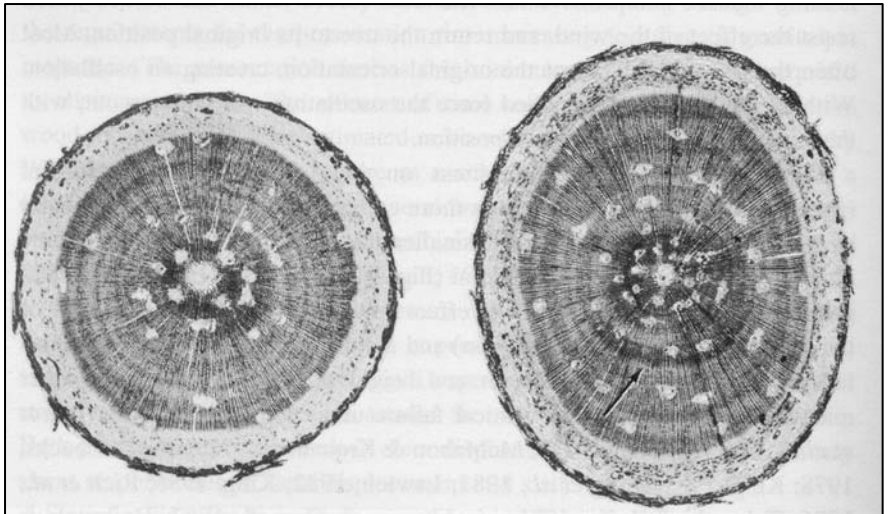


Fig. 14.5. Hypocotyl transverse sections of six-month-old *Pinus taeda* seedlings. *Left*: Control seedling with equal number of tracheids along all radial axes. *Right*: Mechanically perturbed seedling showing eccentric radial growth due to increased tracheid production along the long axis. The arrow points to an arc of thick walled tracheids perpendicular to the direction of perturbation and may have been induced by stem displacement to the gravitational vector rather than the actual flexural motion. Reproduced from Telewski & Jaffe (1981) with the permission of the publisher (National Research Council Canada)

TREE AS MAST, SAIL, and ANCHOR
How strong is each component?
How will each component respond in wind ?

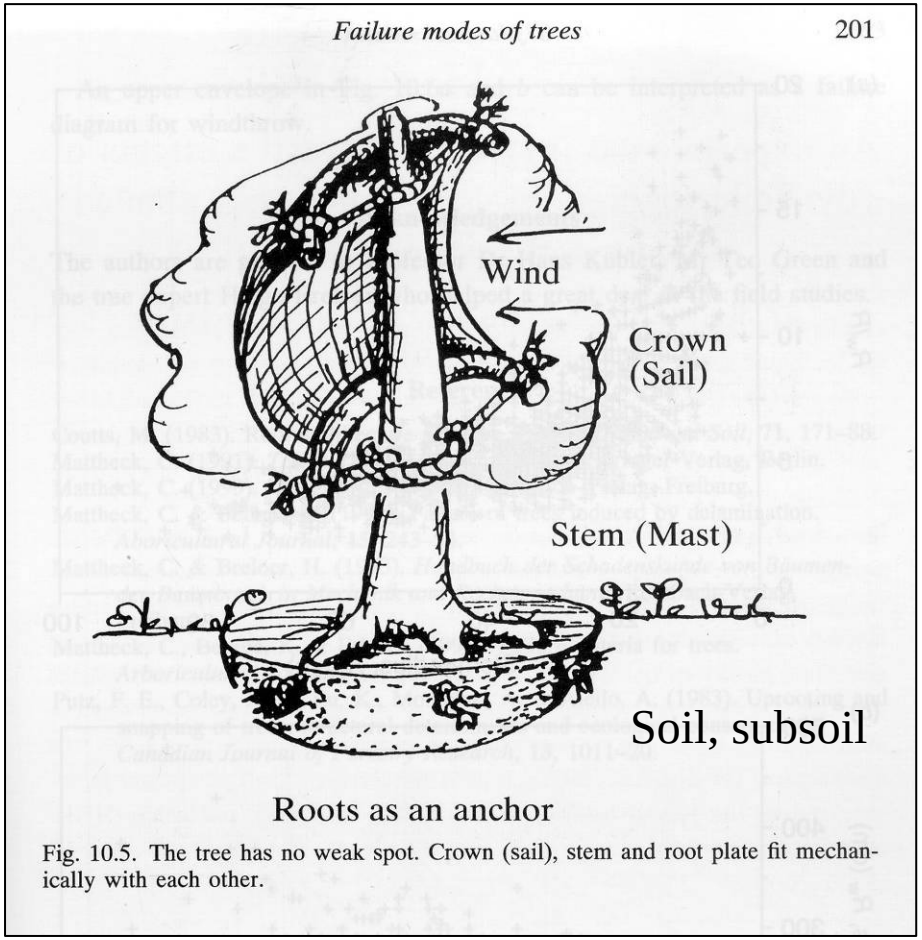


Fig. 10.5. The tree has no weak spot. Crown (sail), stem and root plate fit mechanically with each other.

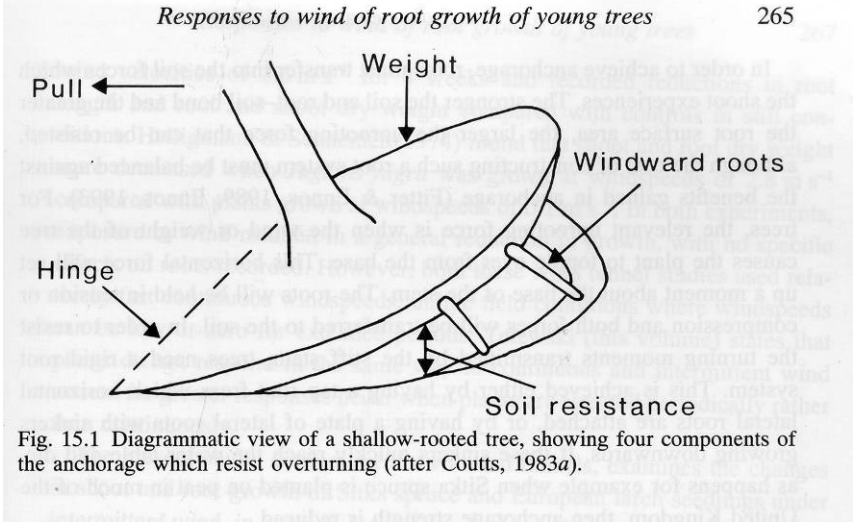


Fig. 15.1 Diagrammatic view of a shallow-rooted tree, showing four components of the anchorage which resist overturning (after Coutts, 1983*a*).

Trees can fail at any of these points, whichever is currently weakest

Examples

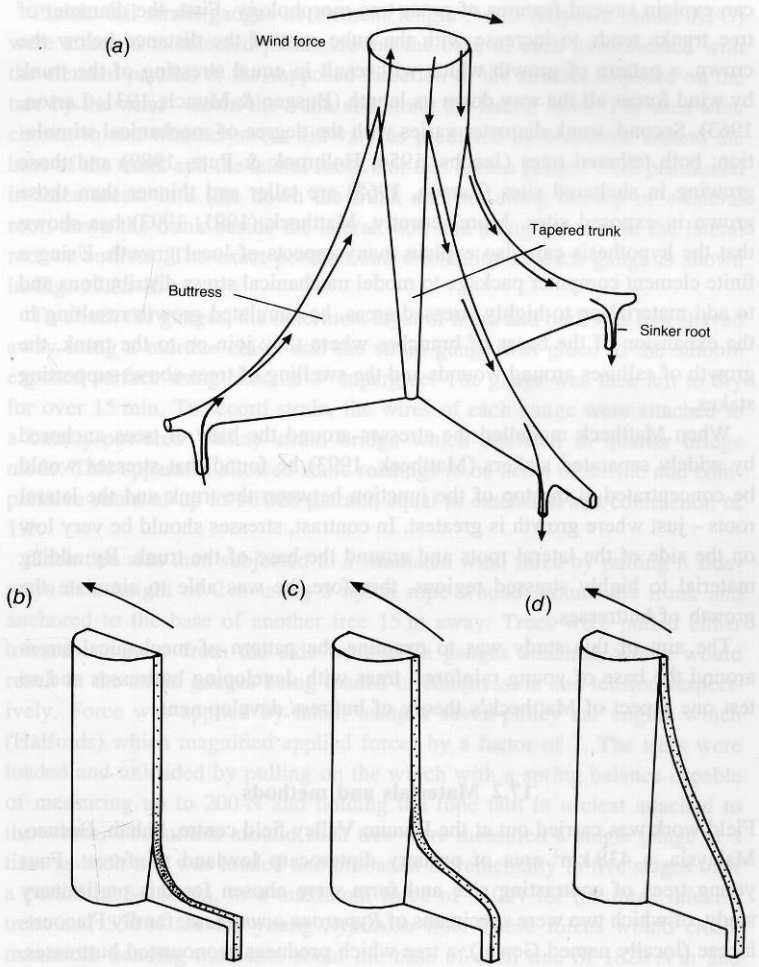


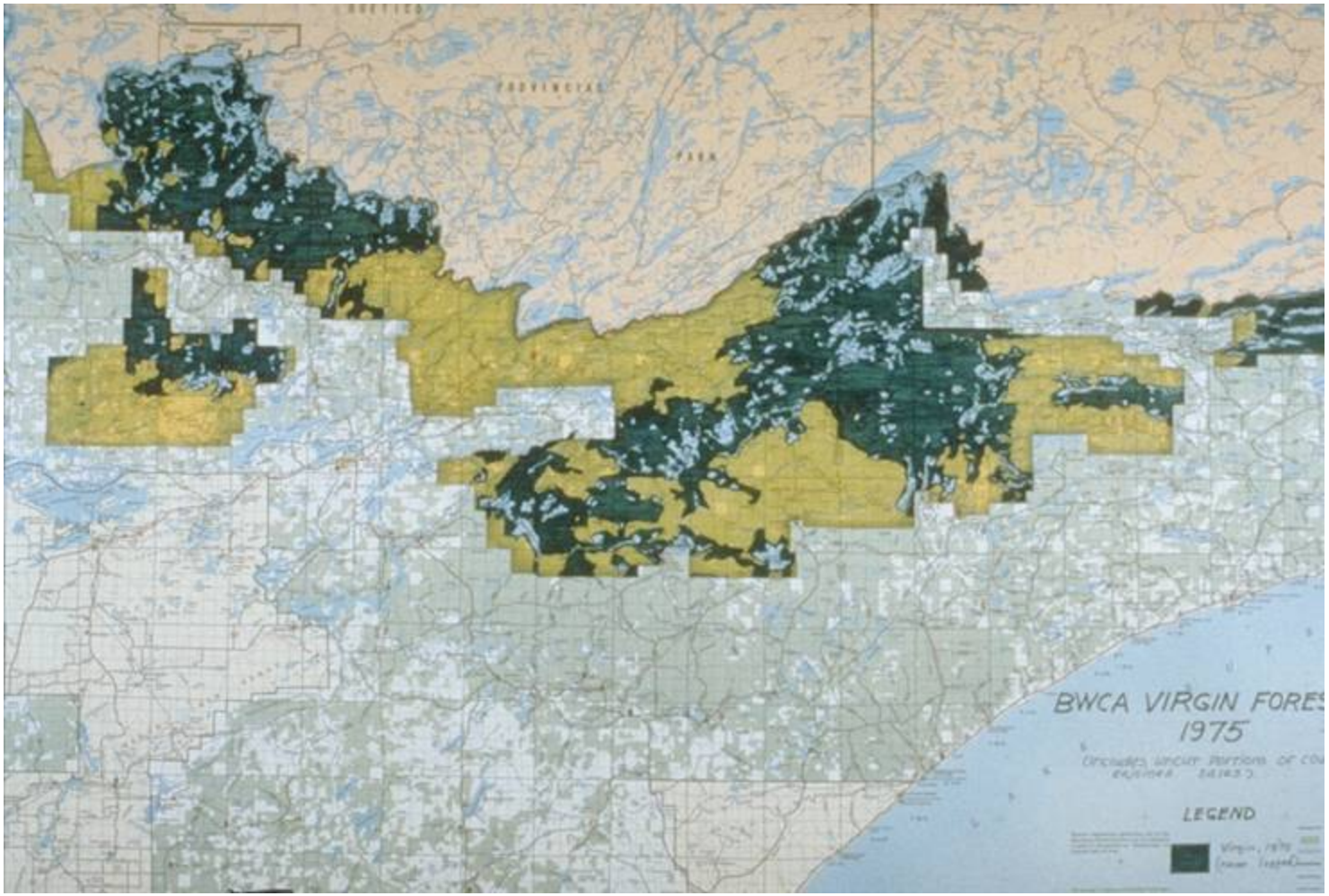
Fig. 17.1. Mattheck's model for the function and development of buttresses. If a tree is pushed over by the wind (*a*) the bending force is transmitted smoothly to lateral sinker roots by the buttresses. Windward sinkers resist upward forces and the buttress is put in tension while leeward sinkers resist downward forces and the buttresses are put in compression. (*b*), (*c*) and (*d*) show successive stages in Mattheck's simulation of buttress development. When the trunk is pulled over stress is concentrated at the top of the junction between the lateral root and the trunk (stippling). Growth in heavily stressed regions (*b*) results in the formation of buttresses (*c* and *d*) and a great reduction in stress concentrations.

Foliar damage from wind

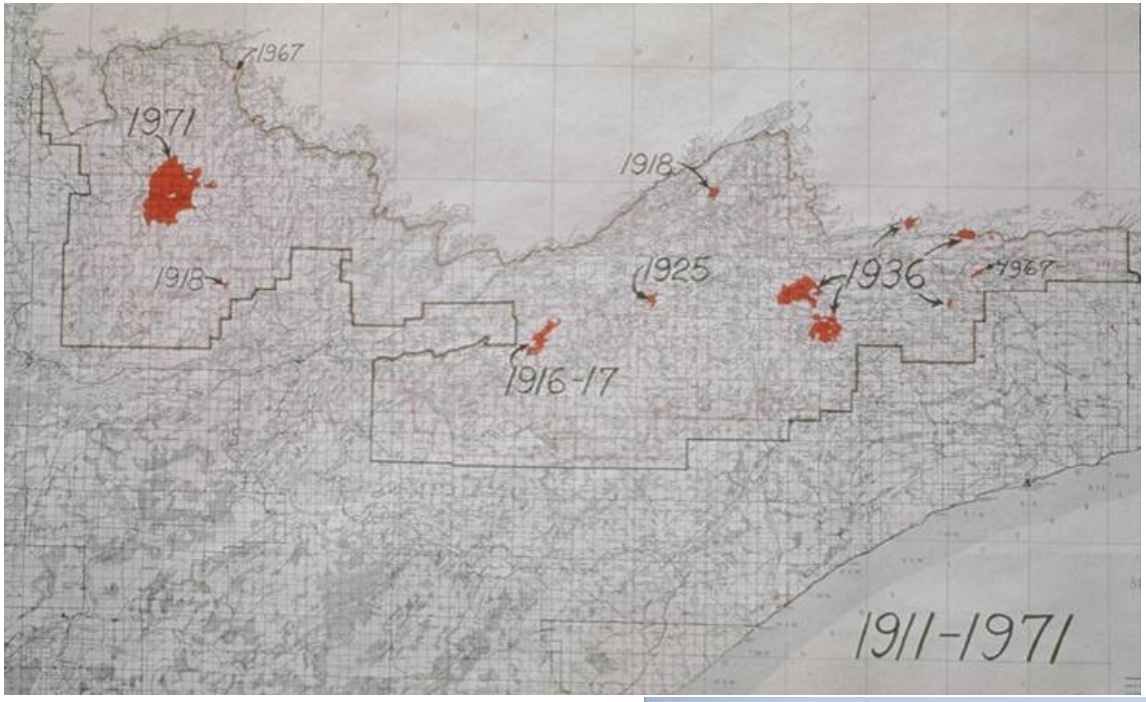
Mechanisms of tolerating extreme wind:

- Swaying or flexure
- Species
- Crown architecture
- Streamlining of crown
- Influenced by stand history and development
- Previous damage or disease

Boundary Waters case study of wind damage to boreal forest



Unlogged forests of the BWCAW (dark green)—Bud Heinselman



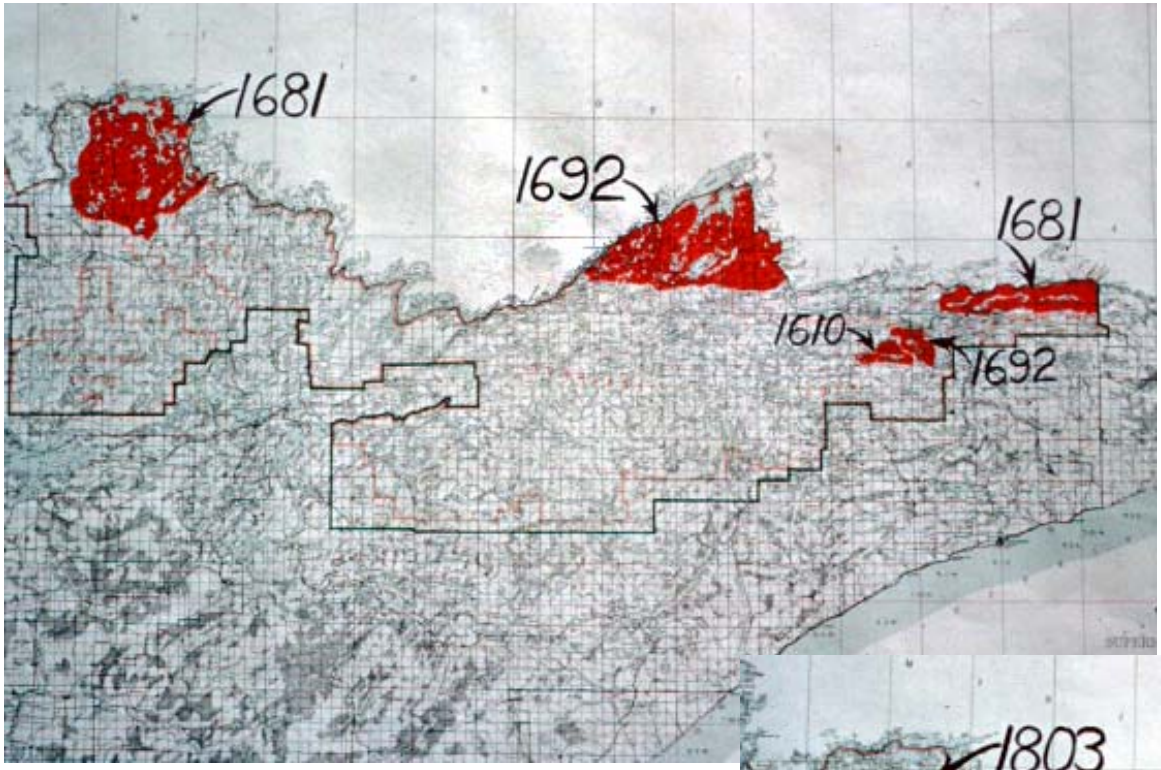
190-year-old jack pine
as a result of fire exclusion
during the 20th Century

Lee Frelich

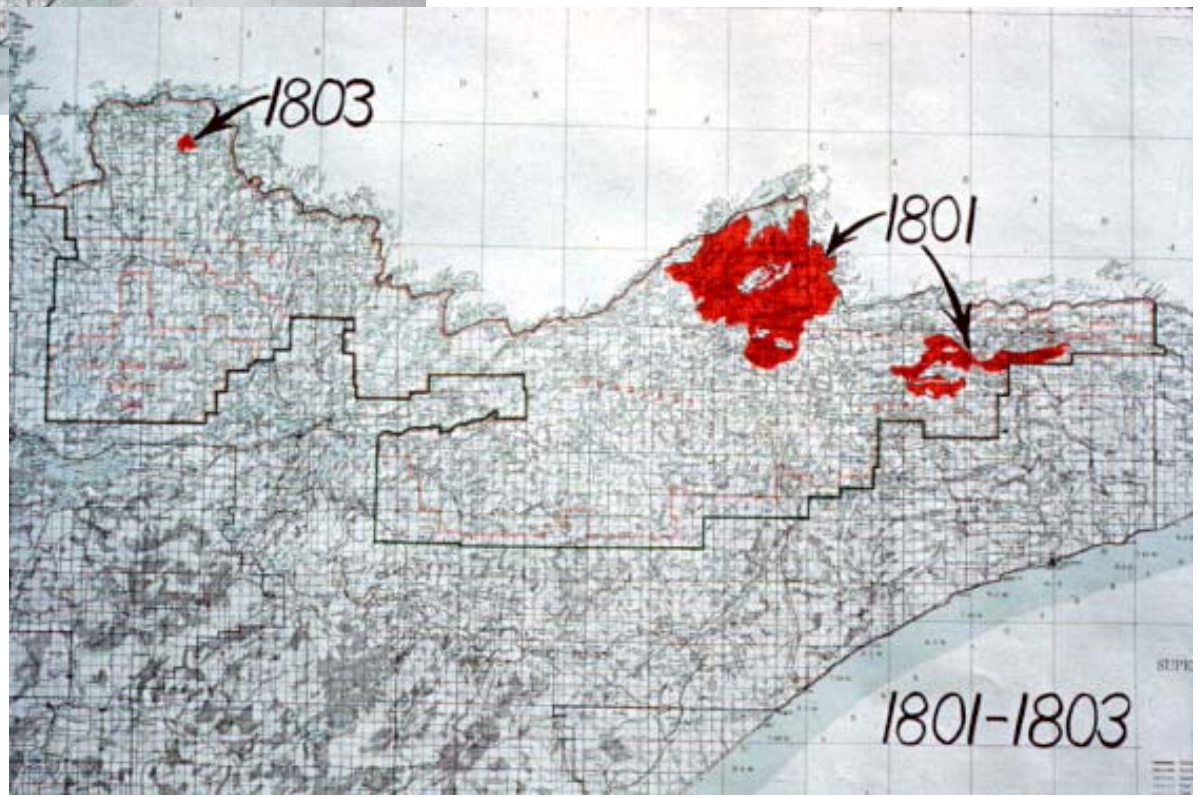
White and red pine in the boreal forest occupy areas with less than average fire intensity—peninsulas, islands and lakeshores

Bud Heinselman

Bud Heinselman



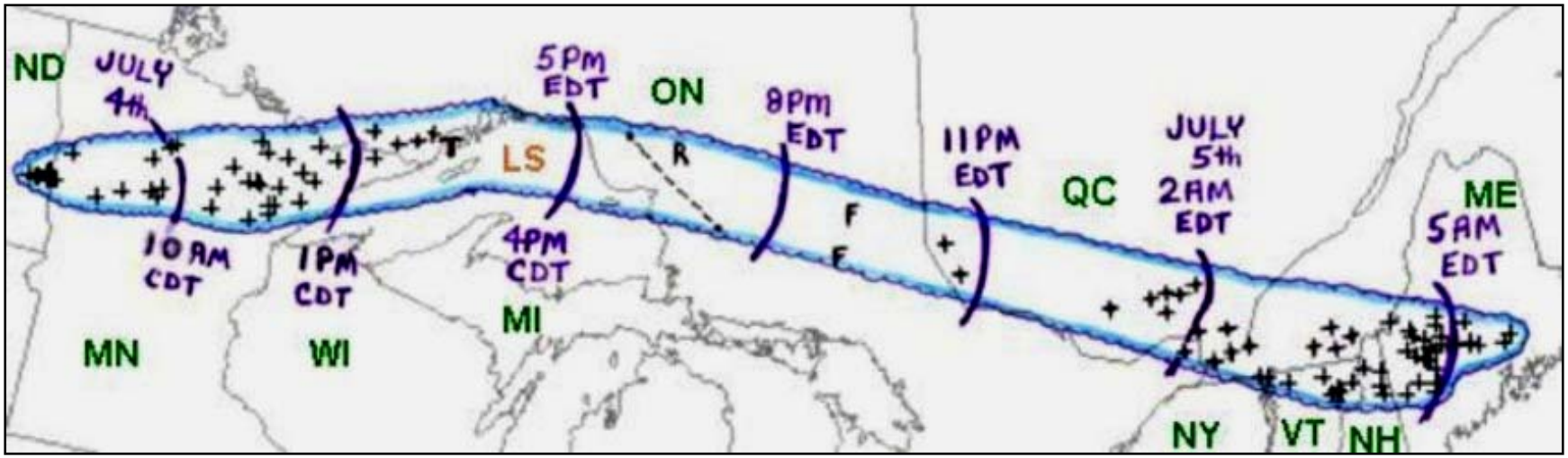
Heinselman's area burn maps



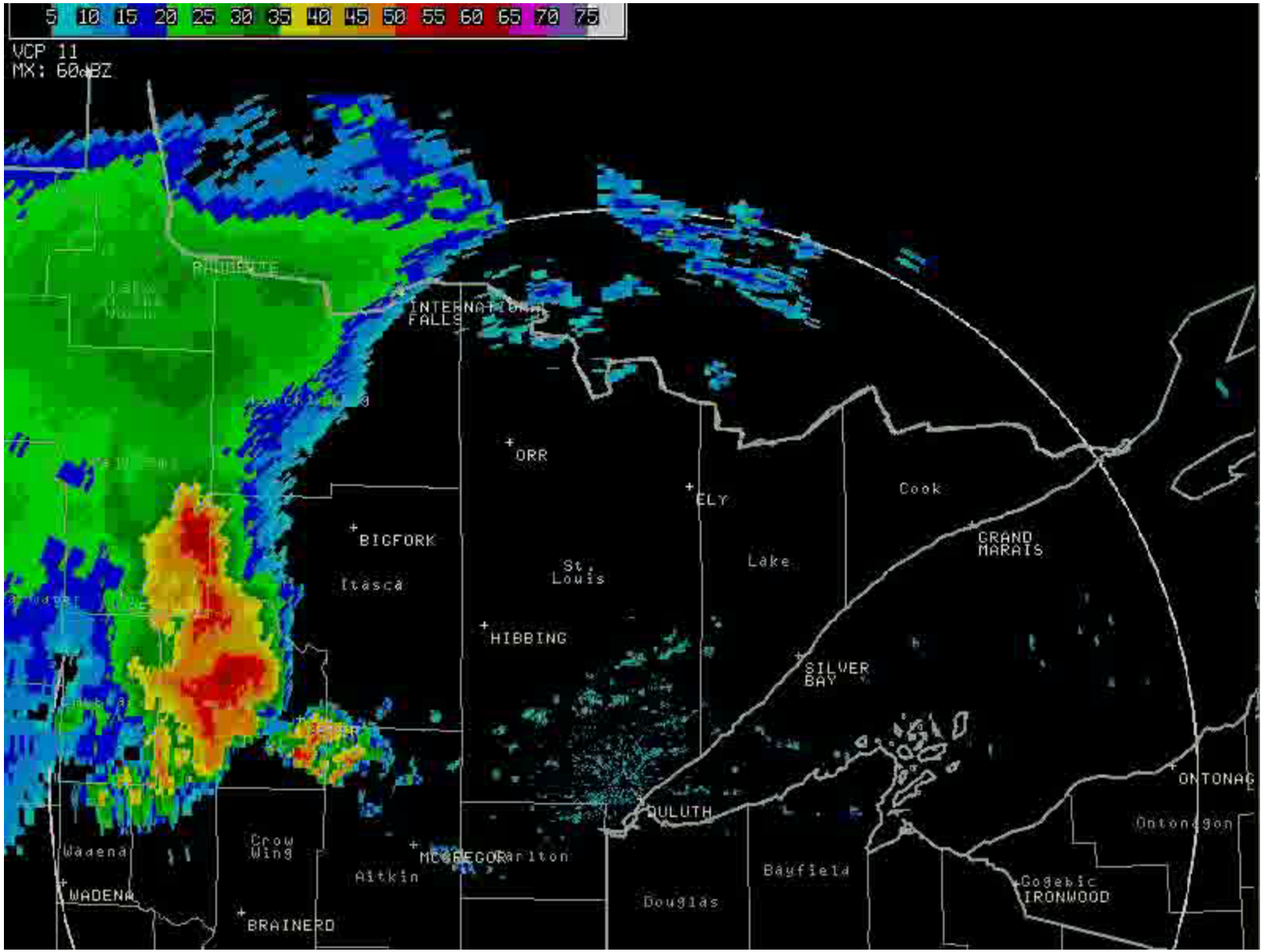
Supercell derecho in progress with intense long-lasting wind and torrential downpour

From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

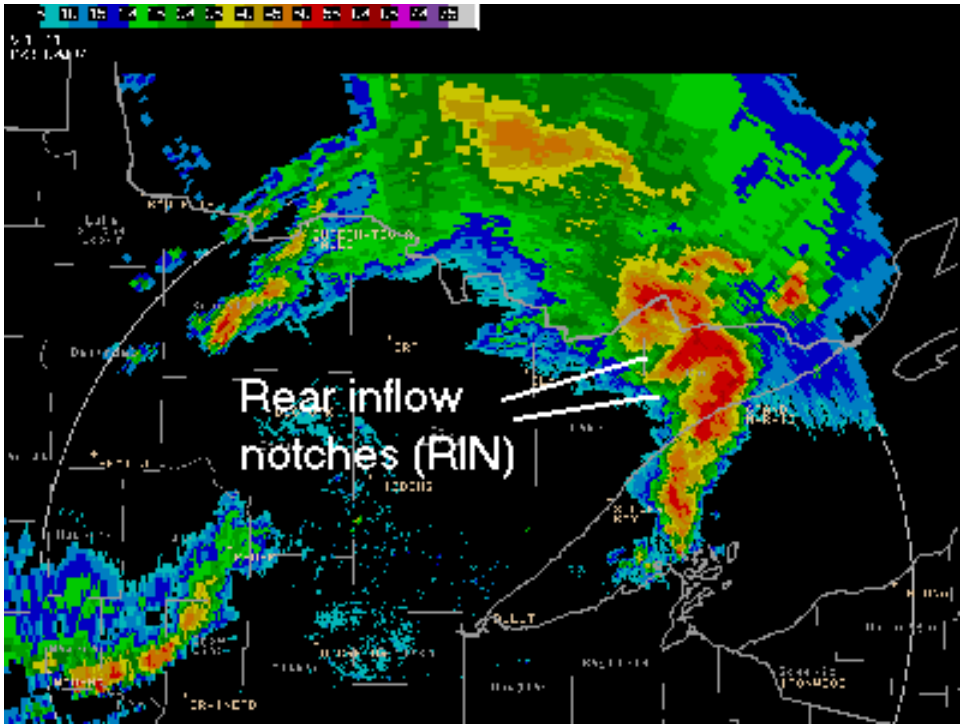
The BWCAW derecho, July 4, 1999:
a combination bow echo and packwash derecho



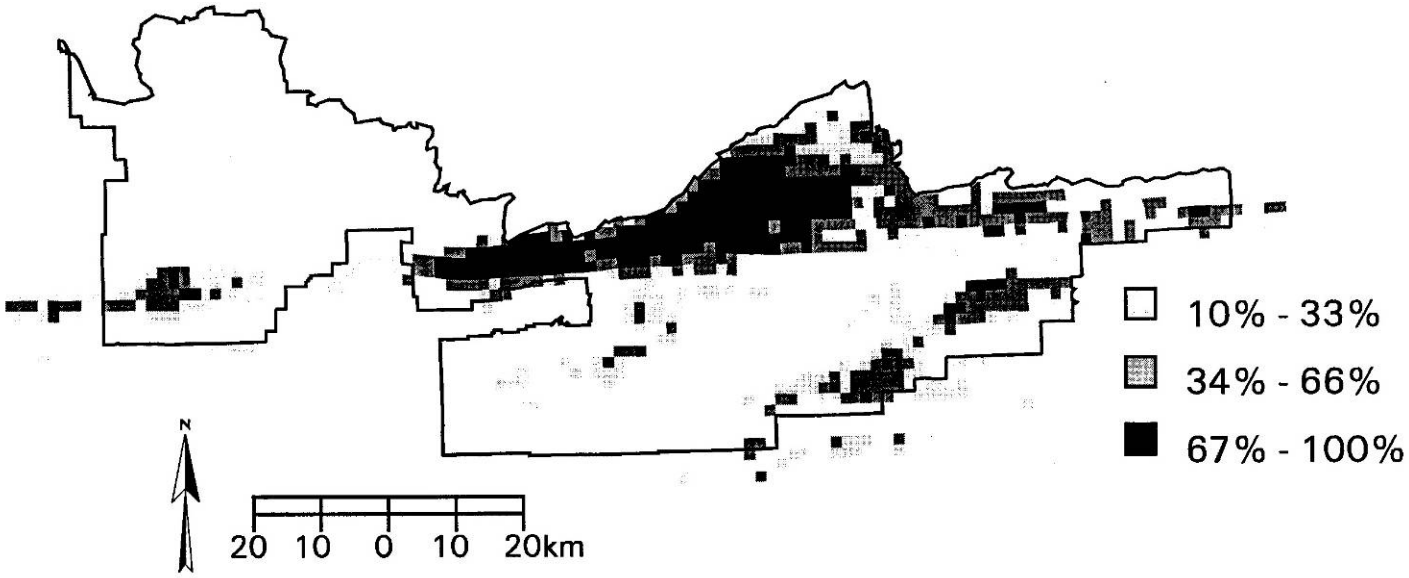
From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos

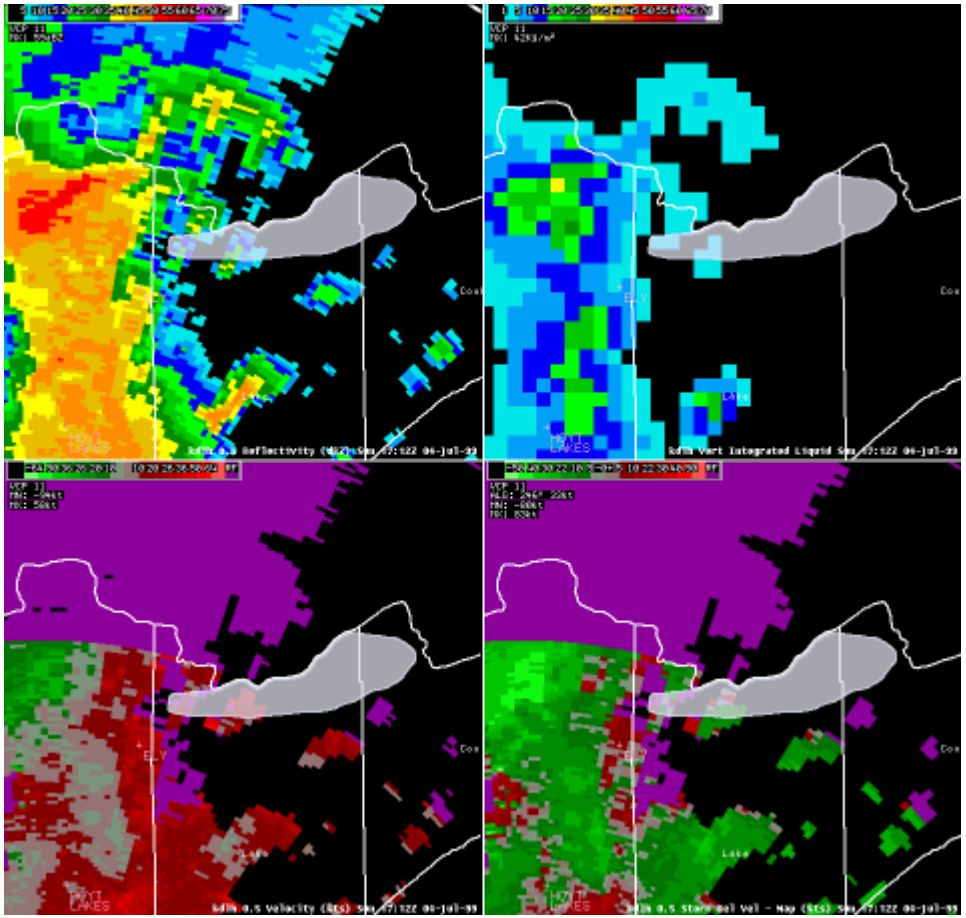


From: R.H. Johns and J.S. Evans: www.spc.noaa.gov/misc/AbtDerechos



Doppler radar image (above) July 4, 1999, and damage swath (below)





Velocity from doppler radar—note rotation in lower left image

Peter S. Parke and Norvan J. Larson—National Weather Service, Duluth

Minneapolis Star tribune

Minneapolis Star tribune

Damage from the July 4, 1999 supercell derecho in the BWCAW

Dave Hansen

1595-origin red pine still standing

Dave Hansen, University of MN
Agricultural Experiment Station

Dave Hansen

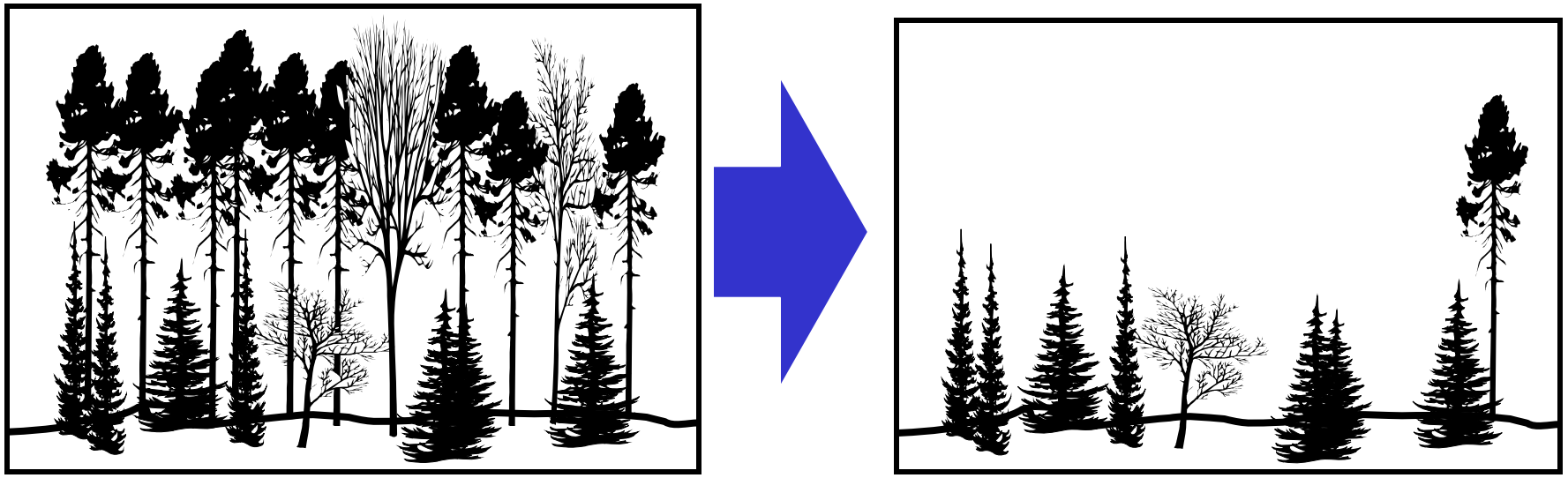
The 1999 big blowdown was the most severe thunderstorm ever recorded in several ways:

- A bow echo, rotating head and two rear inflow notches all at once
- 400,000 acres of forest leveled and several million acres damaged
- Several F4 tornados
- Path length of 6000 miles including MN to Maine, time spent over the Atlantic and reentry into the U.S. in South Carolina
- 6000 cloud to ground lightning strikes per hour between MN and Maine
- Up to 7 inches of rain caused unique flooding disturbances

Differential susceptibility of near-boreal tree species

Roy L. Rich
Peter B. Reich
Lee E. Frelich

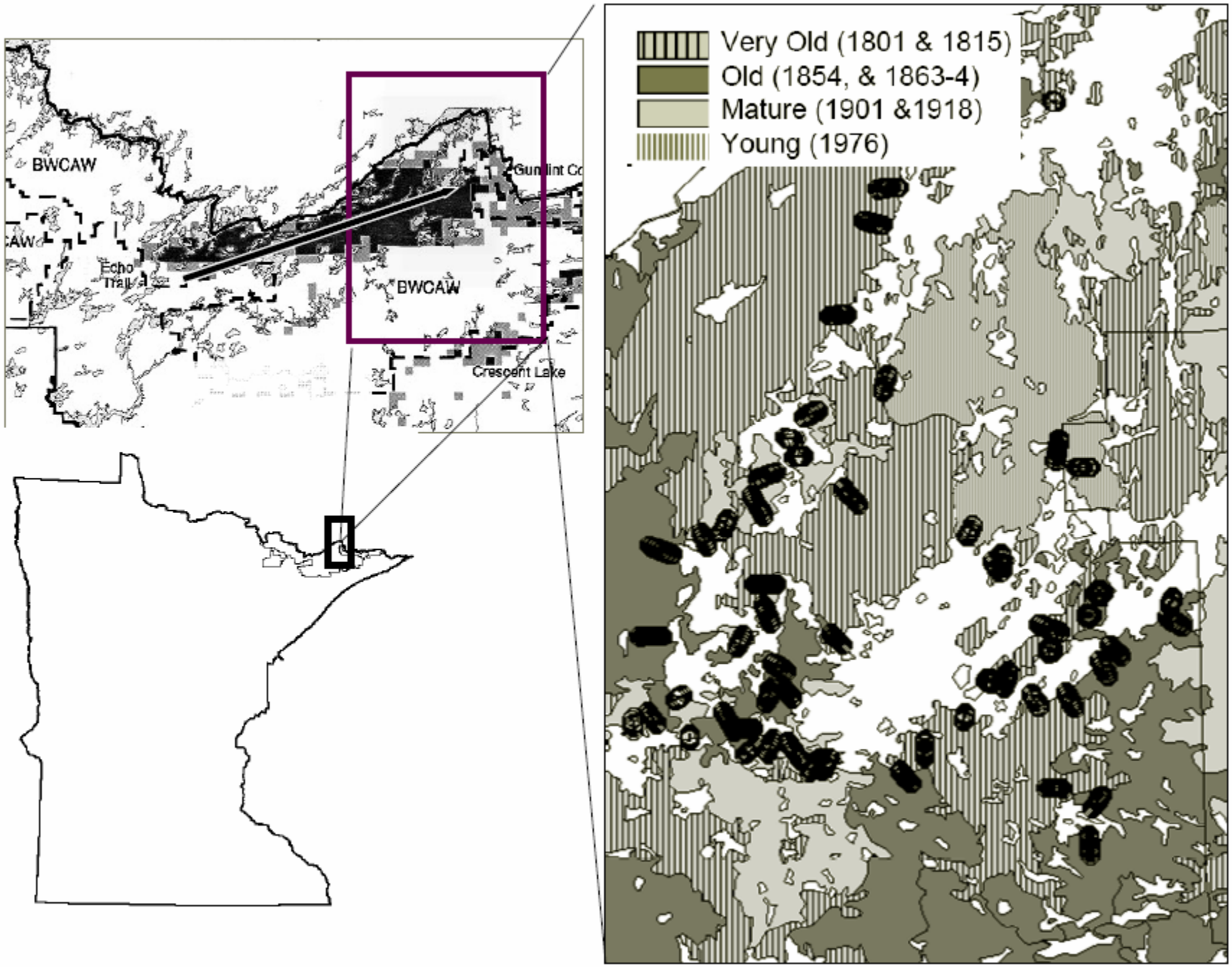
Status: manuscript to be submitted for publication during September 2004



Mechanisms:

1. Direct selection of resilient canopy trees

2. Release of understory regeneration

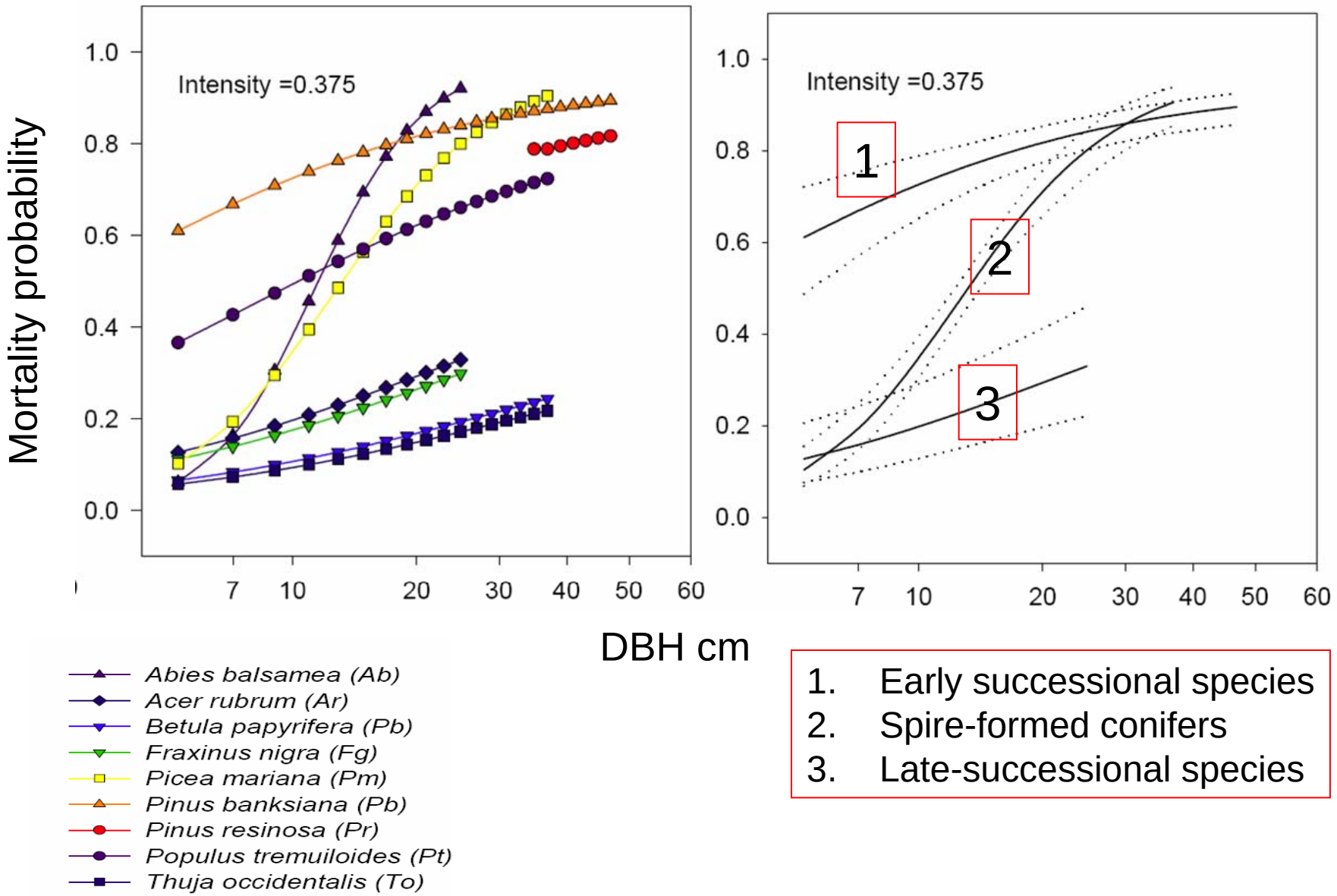

Very Old (1801 & 1815)
Old (1854, & 1863-4)
Mature (1901 &1918)
Young (1976)
BWCAW
Echo Trail
BWCAW
Crescent Lake

Susceptibility model to predict mortality probability

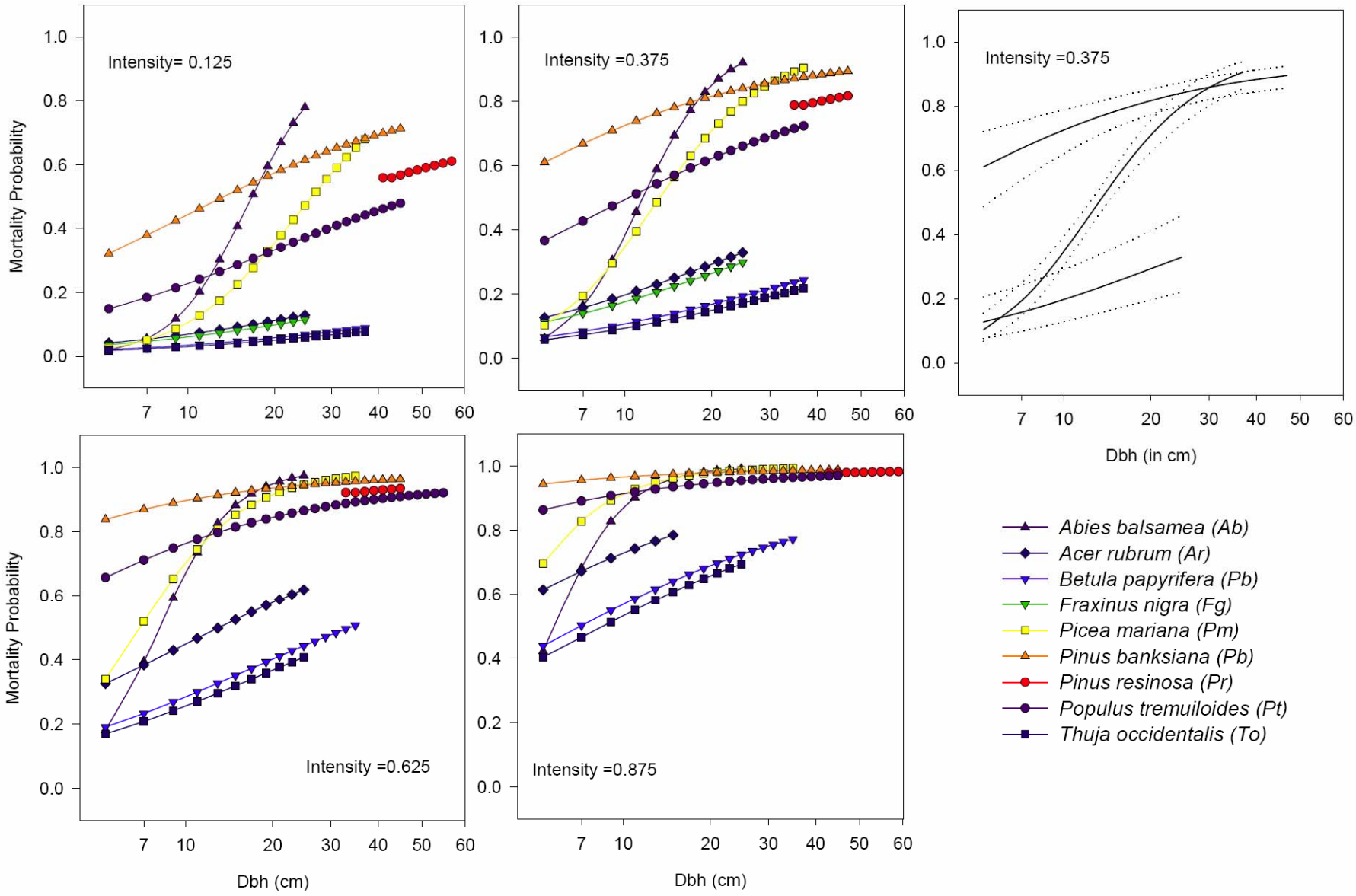
Logit (mortality) = -.67(ln dbh) –6.59(sss) +3.819 (ln dbh*sss)+ B(spp)+ B(age) +

(spp:ln dbh + spp:lss for BF and BS only)
(spp:age for QA only)

3673 canopy trees from fine scale plots
9 species



1. Early successional species
2. Spire-formed conifers
3. Late-successional species


Intensity= 0.125
Intensity =0.375
Intensity =0.375
Intensity =0.625
Intensity =0.875
Mortality Probability
Mortality Probability
Dbh (cm)
Dbh (cm)
Dbh (in cm)
1.0
0.8
0.6
0.4
0.2
0.0
7
10
20
30
40
50
60
Abies balsamea (Ab)
Acer rubrum (Ar)
Betula papyrifera (Pb)
Fraxinus nigra (Fg)
Picea mariana (Pm)
Pinus banksiana (Pb)
Pinus resinosa (Pr)
Populus tremuiloides (Pt)
Thuja occidentalis (To)

Summary of Differential Susceptibility

Differential mortality is evident among tree species in the canopy. Direct selection of canopy trees occurred.

DBH has an important effect; susceptibility increases with tree size

Three groups of species are evident from these projections.

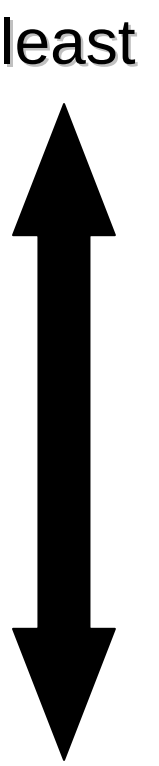
Low: Cedar, Paper Birch, Red Maple, and Black Ash

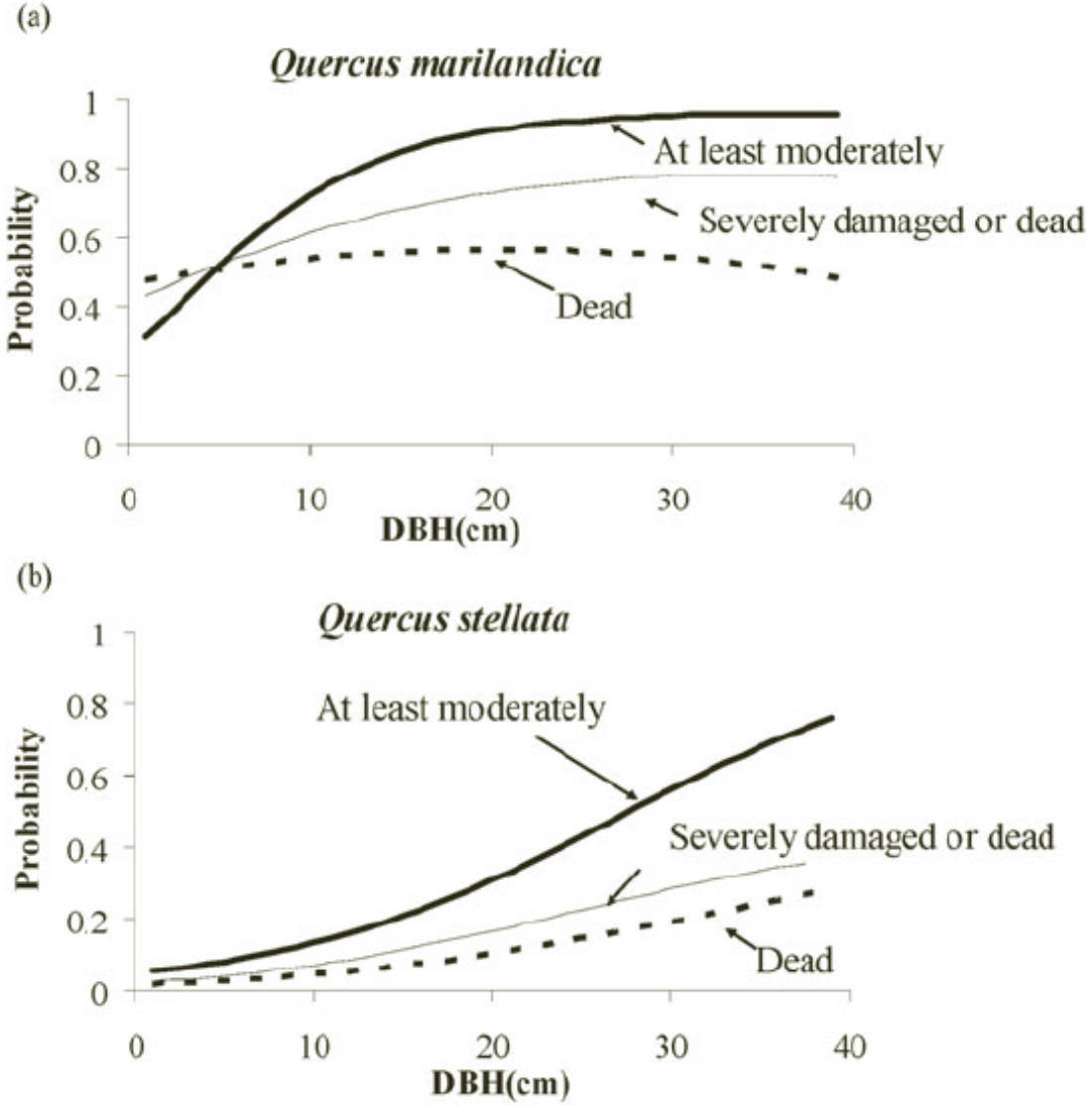
High: Jack Pine, Aspen Red Pine

Shifting: Black Spruce, Balsam Fir

Near- boreal Shade Tolerance

Pinus banksiana-	*Jack Pine*
Populus tremuloides-	*Aspen*
Pinus resinosa-	*Red Pine*
Betula papyrifera-	*Paper Birch*
Picea glauca-	*White Spruce*
Pinus strobus-	*White Pine*
Acer rubrum-	*Red Maple*
Picea mariana-	*Black Spruce*
Abies balsamea-	*Balsam Fir*
Thuja occidentalis-	*White Cedar*



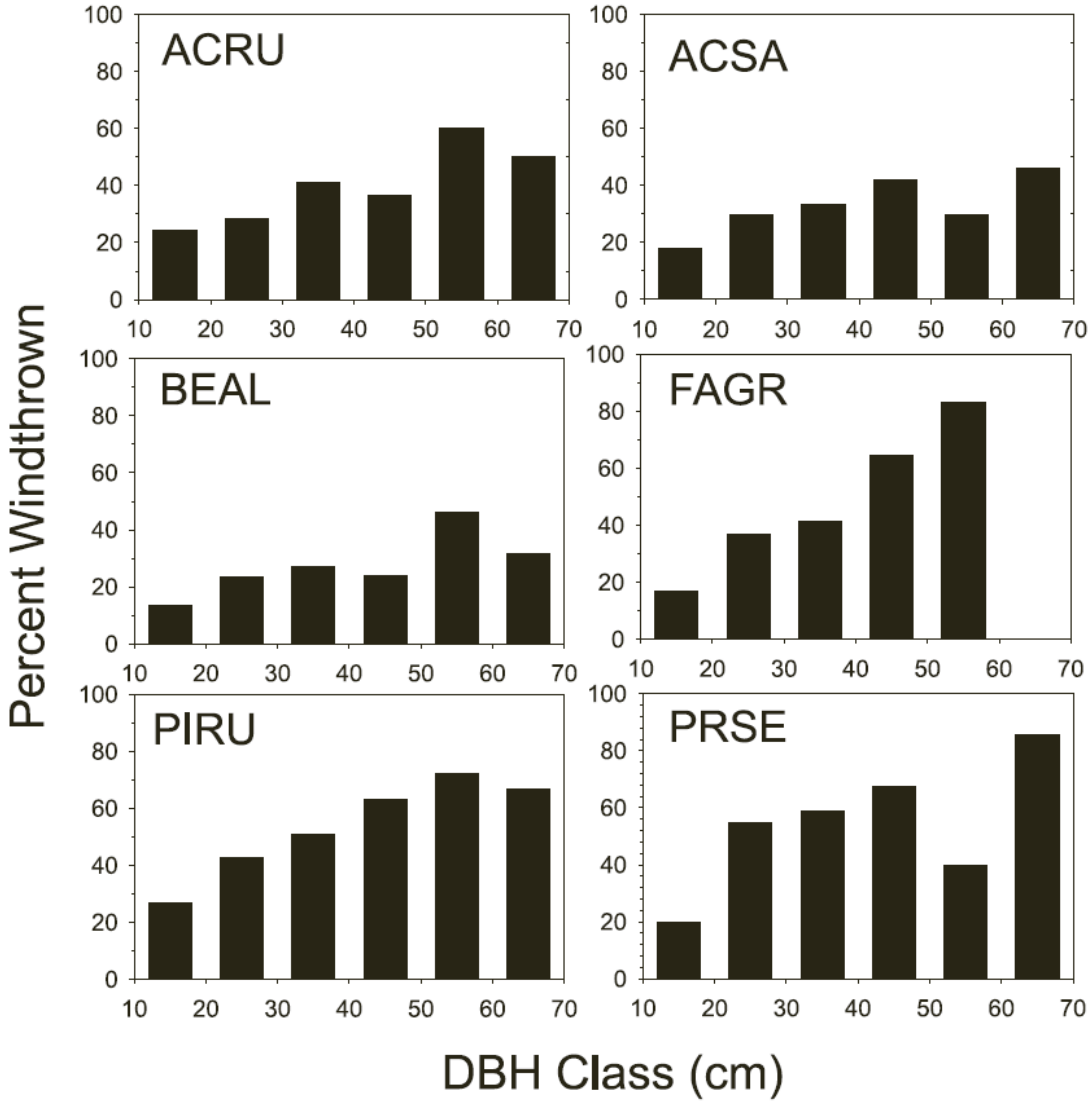


Other case studies: Tornado damage in OK oak forests

(From Shirakura, Sasaki, Arevalo and Palmer, J. Vegetation Sci. 17: 347-352)

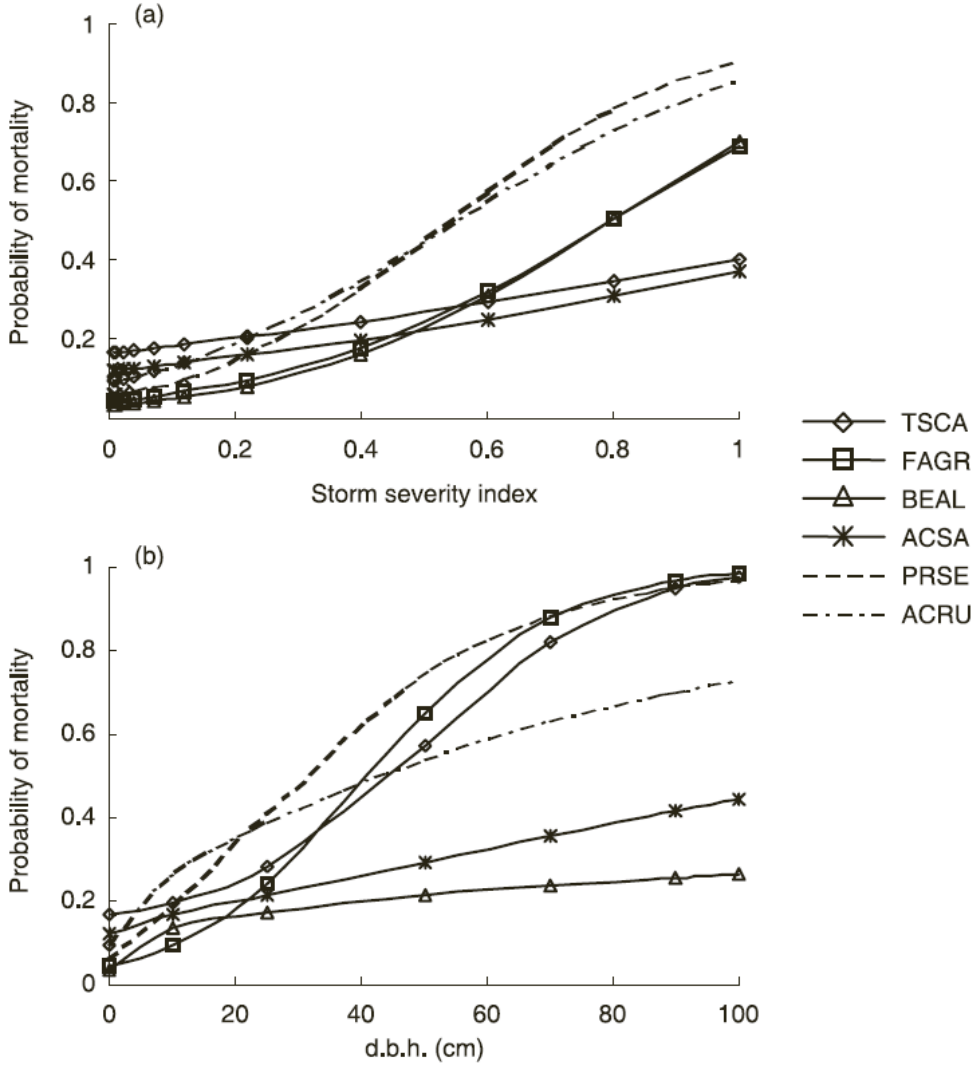
Effects of dbh on windthrow in northern hardwoods

(from Canham, Papaik and Latty Can J. For Res. 31: 1-10)



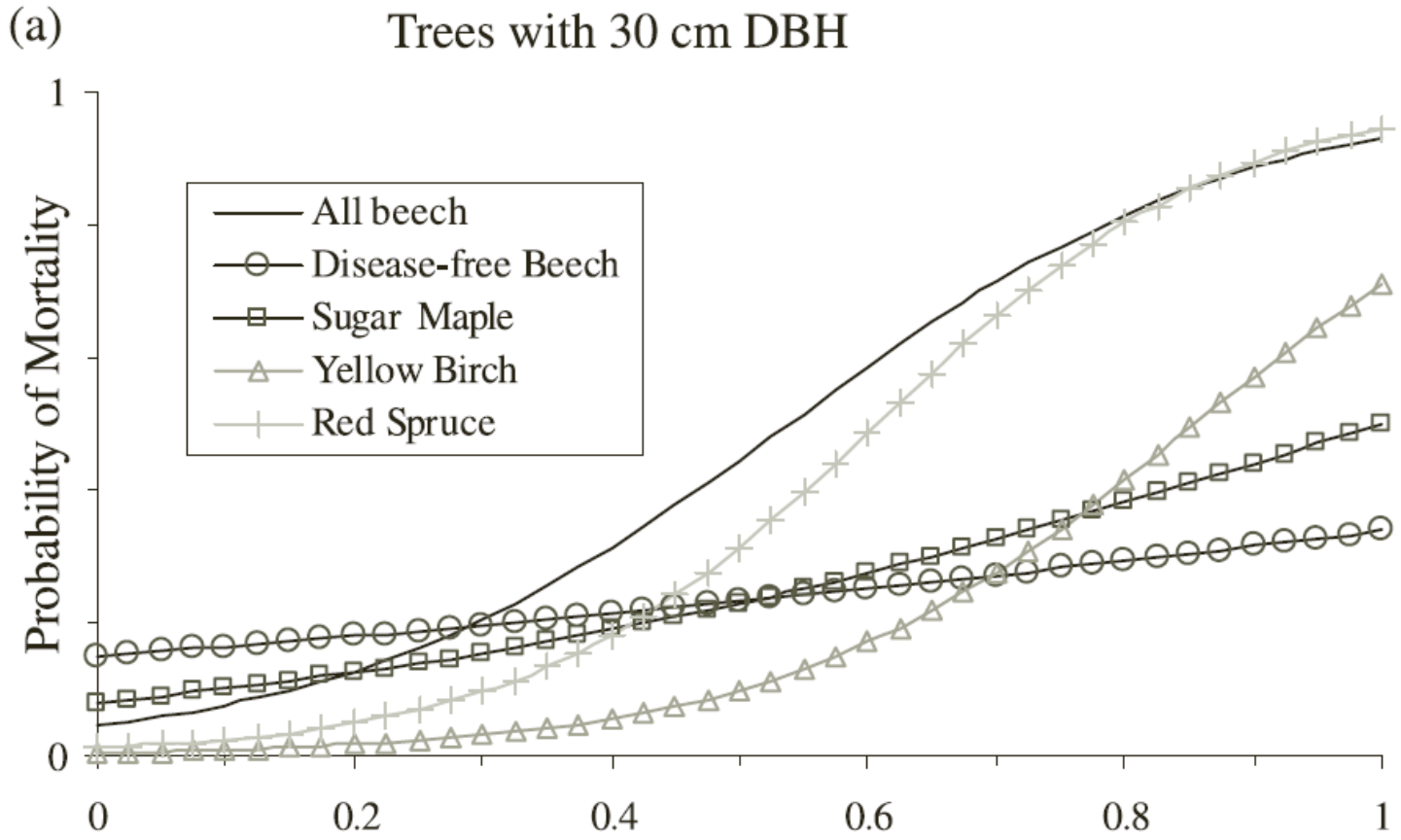
Effects of tree diameter and storm severity on windthrow mortality in northern hardwoods

(from Papaik and Canham Journal of Ecology 94: 1011-1026)



Effects of tree disease on blowdown mortality

(from Papaik, Canham, Latty and Woods, Can J. For Res 35: 1832-1843)



Four odd species of trees in the Midwest:

White pine
American Basswood
Black Ash
Cottonwood

All reach their maximum girth in the Midwest

Black ash, Porcupine Mountains, MI

Paul Jost

Eastern Cottonwood, MN

John Kneurr

White pine, Porcupine Mountains, MI

Paul Jost

American basswood, Porcupine Mountains, MI

What trait do American basswood, black ash, cottonwood and White pine share?

Answer: brittle wood

How does brittle wood allow these trees to get big?

Answer: They shed branches and grow a new crown after the storm

Black Ash in Upper MI

Paul Jost

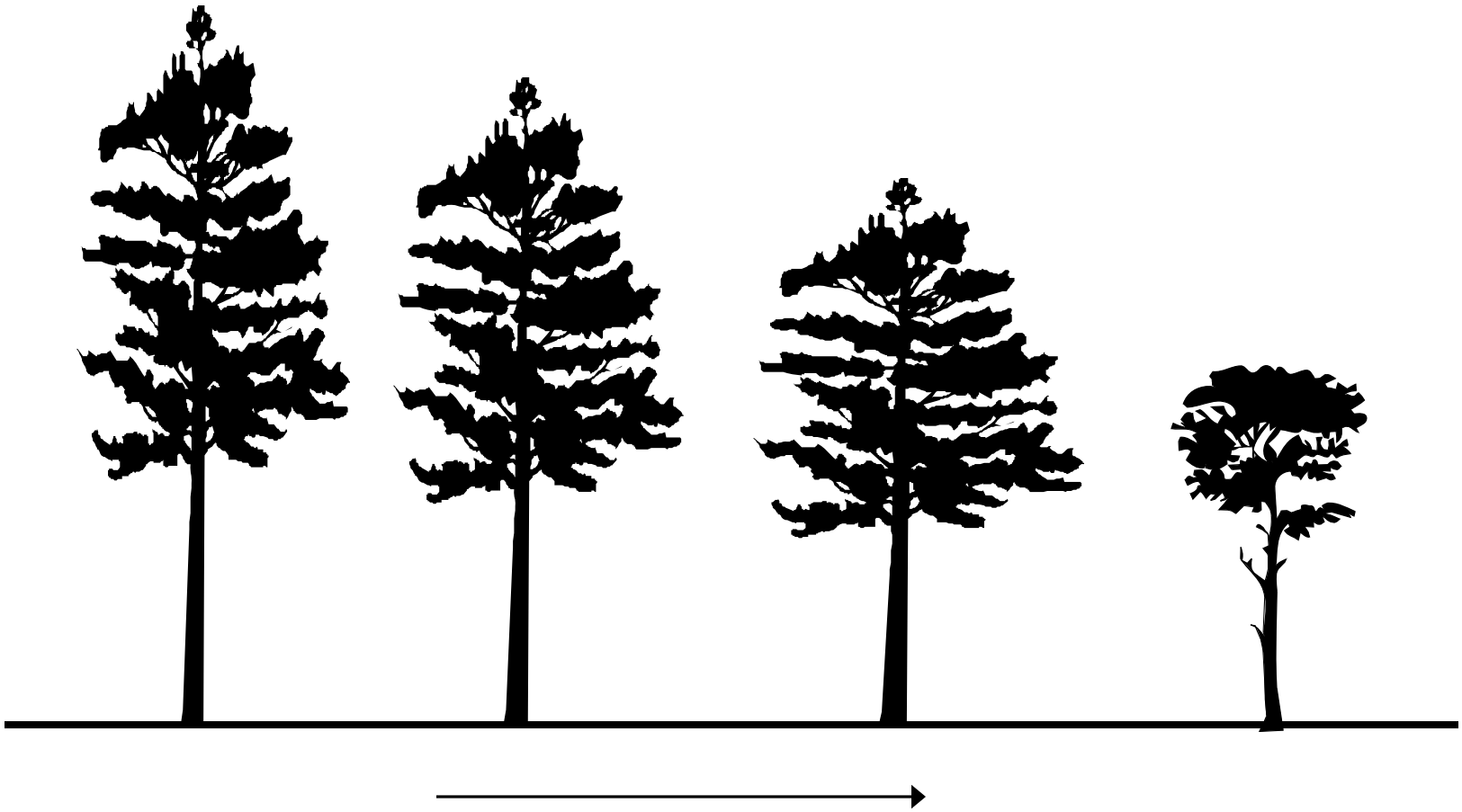
Snapping of aspen
at trunk cankers

Minneapolis Star tribune

Dave MacFarlane

Paper birch remaining after 1999 blowdown as a result of their flexibility

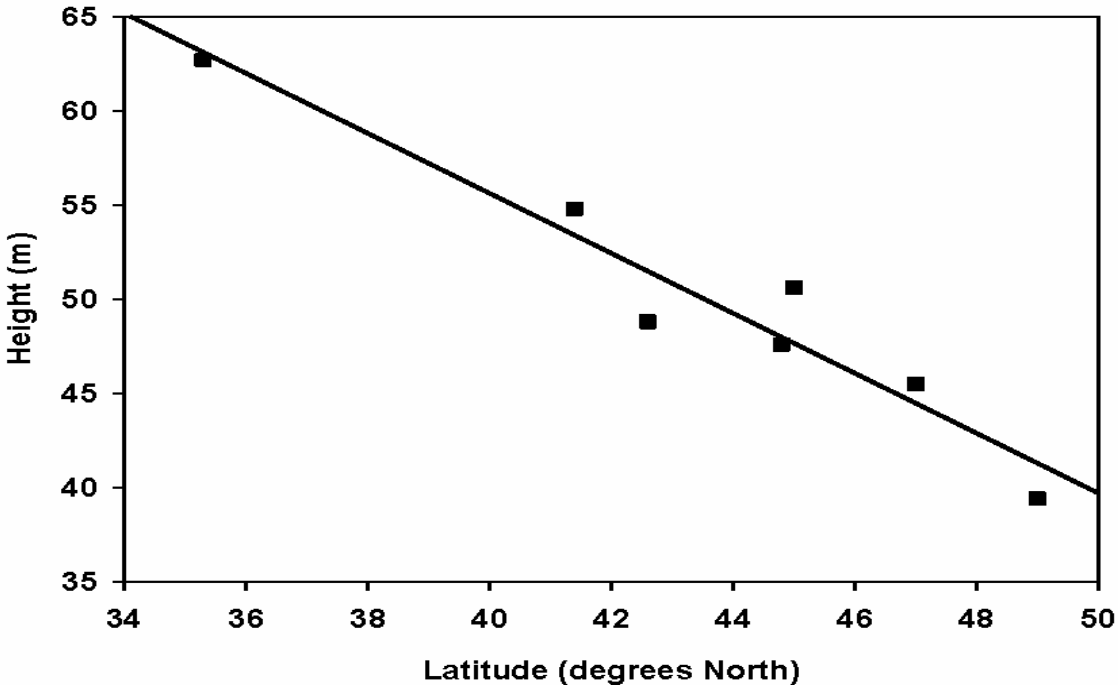
Tree height is subject to strong genetic control, and is therefore subject to change with increasing latitude, elevation, or decreasing soil depth or soil quality.



Colder climate and/or poorer soils, and decreasing susceptibility to wind

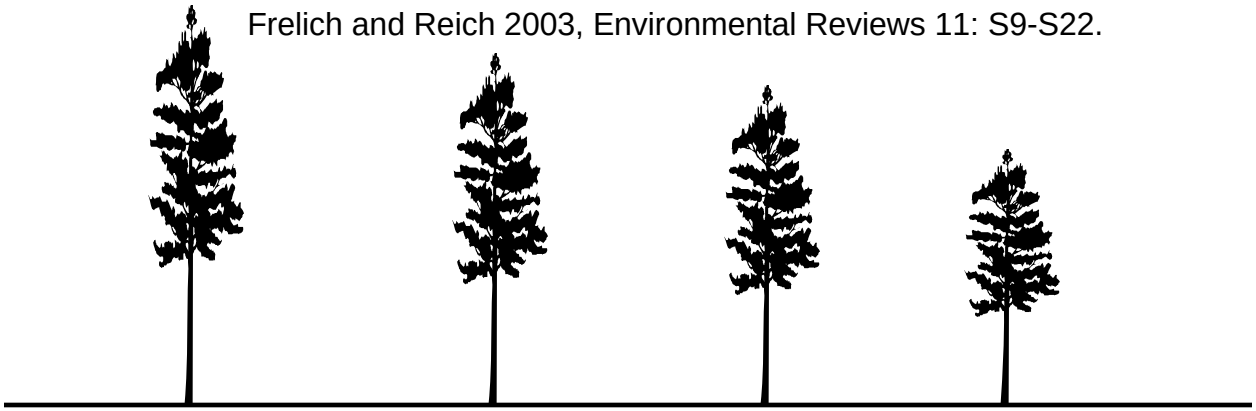
Hardwoods, Mohawk
Trail State Forest, MA

Trees have a higher H:D ratio
at more southerly latitudes



Frelich and Reich 2003, Environmental Reviews 11: S9-S22.

Maximum white pine height follows a latitudinal gradient that is likely a surrogate for shorter growing season in the north



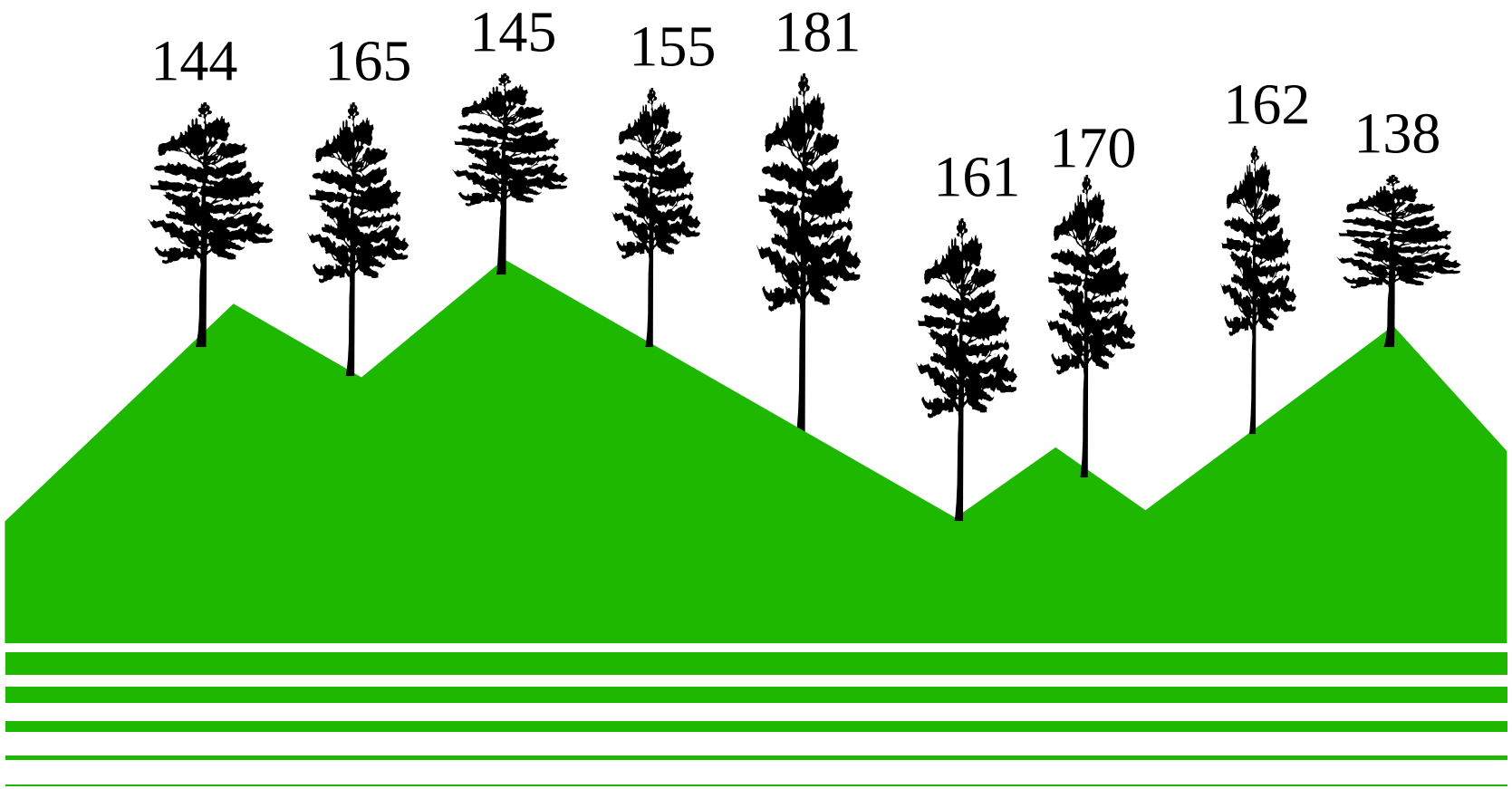
Great Smokies, NC 207 feet

Cook Forest PA 181 feet

WI 167 feet

Lost 40-MN 138 feet

Tallest trees are on side slopes that are neither flooded nor drought stressed



Pitch pine, Mount Everett, MA

All other factors being equal:

Susceptibility increases with increasing diameter

Center of gravity is important—lower center of gravity explains why open grown trees are less susceptible

Spire formed conifer and forest grown aspen (artists paint brush shape) with small crown at top are more susceptible than other growth forms

Early-successional species are more susceptible than late-successional species

Well established edge trees are less susceptible due to shorter stature

Trees in the south are more susceptible because they have a greater height:diameter ratio

There is no consistent trend with wood strength and other tree traits—species of trees arrive at low susceptibility by various combinations of traits, such as height:dbh ratio, wood flexibility, wood strength, branch shedding

Synthesis of literature by LEF

Wind speeds of:

60-90 mph—streamlining of foliage and branches, force on tree increases linearly with wind speed

90+ mph—streamlining is maxed out, force on tree increases as an exponential function of wind speed

110+ mph—forest stands are leveled, leaving seedlings and saplings