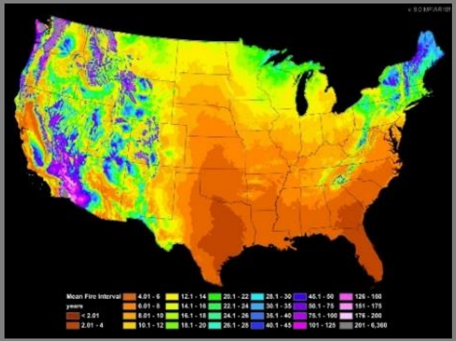
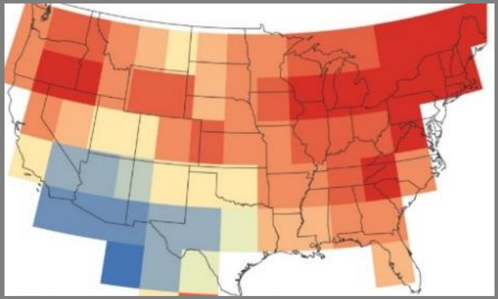
Past and future wildland fire dynamics in the Lake States ecosystems

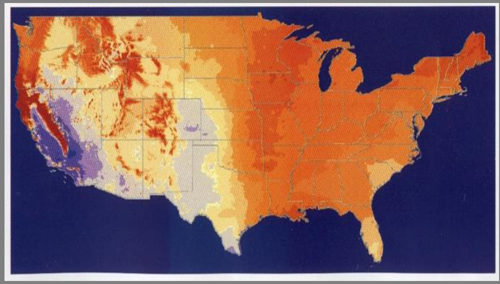
Richard Guyette, Daniel Dey, Michael Stambaugh, Rose-Marie Muzika, Joe Marschall



Collaborators: Theresa Gallagher, Patrick Brose, Frank Thompson, Andy Cutko, Dave Toby, Todd Tisler, Mark Shermax

University of Missouri
USFS Northern Research Station,
Maine Department of Conservation,
Pennsylvania Game Commission,
Chippewa National Forest
Prentiss & Carlisle Inc.





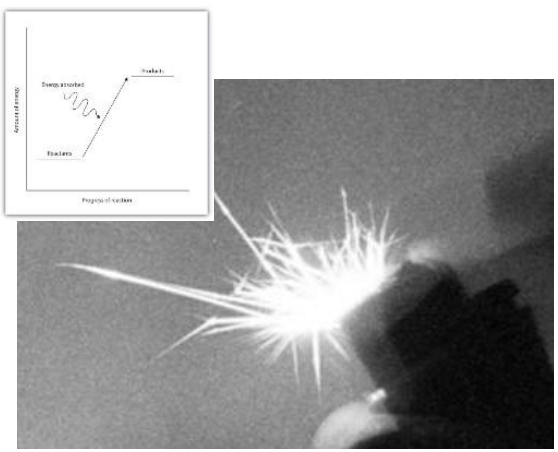
Lake States Fire Consortium
December 17, 2015

Combustion dynamics in ecosystems

Being direct and as close possible to the core of an ecosystem process enables basic understanding. The chemical and physical processes controlling fire in ecosystem combustion are primary. Although records of vegetation, topography, management and many other phenomena relate strongly to fire, it is the dynamics of the fire process itself that are the central to this exothermic reaction in ecosystems.

(energy in, a spark)

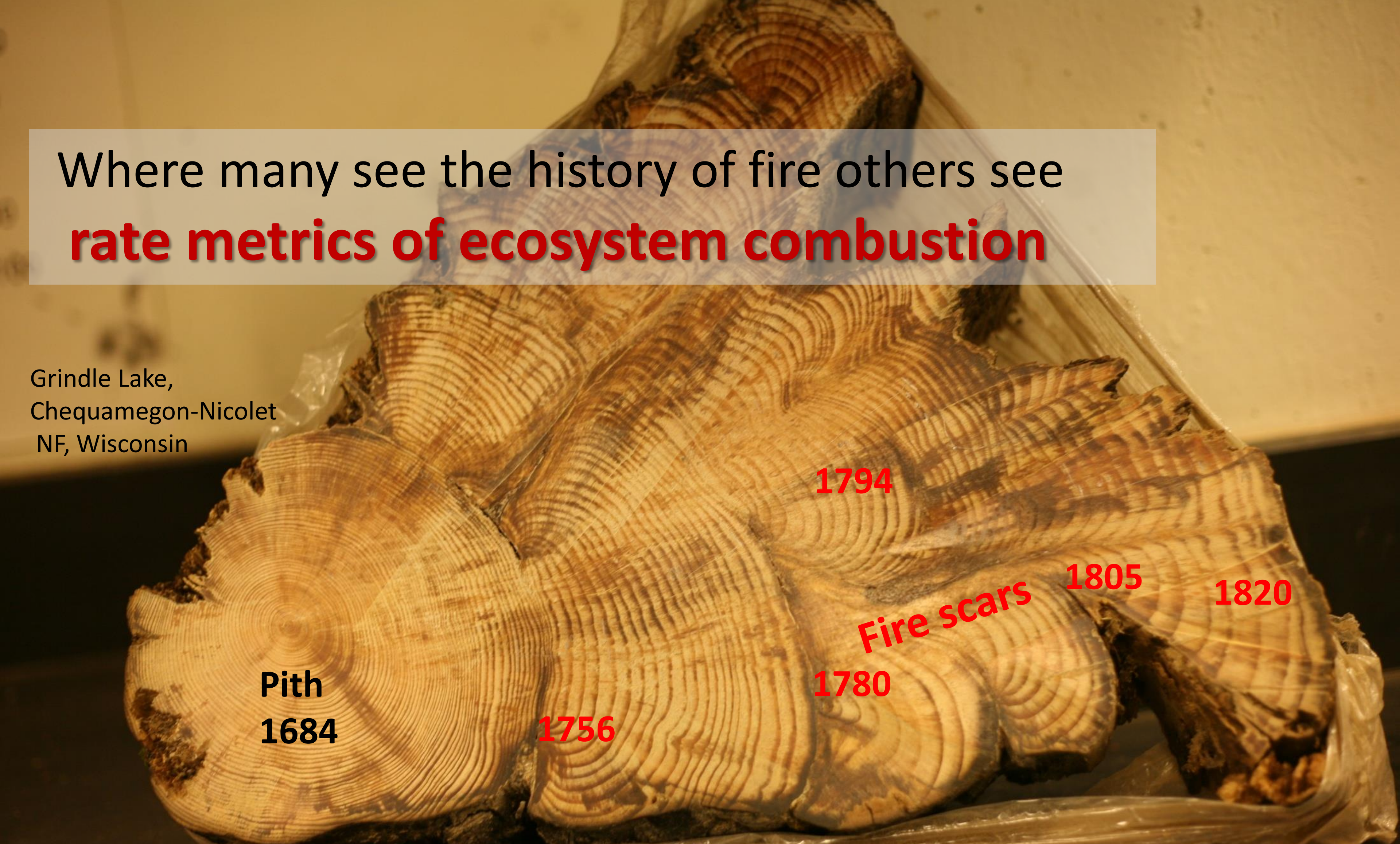
C-H, 100 kj mol^{-1}



(energy out, light & heat)

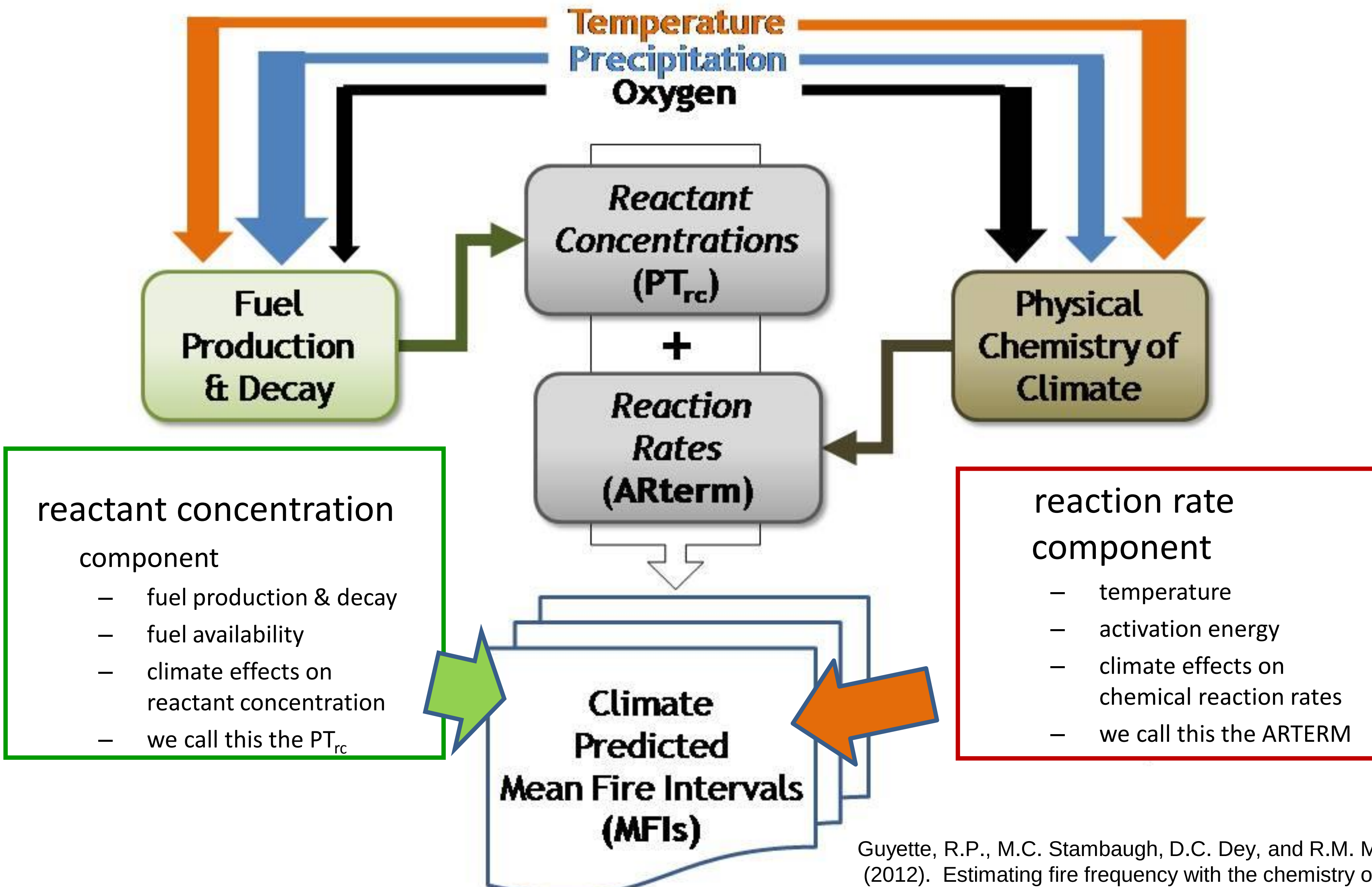
C-H, 413 kj mol^{-1}

Where many see the history of fire others see **rate metrics of ecosystem combustion**



Time & Fire data are long-term records that represent the physical chemistry of combustion in an ecosystem

Spatial climate and fire metrics provide data for ecosystem combustion dynamics



Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335.

Ecosystem combustion model validation and calibration

Physical Chemistry Fire Frequency Model (PC2FM)

How do we get the coefficients ($y = b_o + b_1 x$)
for this hybrid process equation: with empirical data and climate proxies

Multiple regression coefficients bridge and calibrate molecular and ecosystem processes

Physical Chemistry

reaction environment
$k = A_o \exp^{-Ea/RT}$

+

reactant concentration
$rate = [A^x][B^y]$

Fire history

$$MFI = b_o + b_1 A_o \mathbf{e}^{Ea/R\mathbf{T}} + b_2(O_2(1/P^2/T)$$

Statistics

$$MFI = \mathbf{-4.3} + \mathbf{1.7x10^{-28}}(A_o \mathbf{e}^{Ea/R\mathbf{T}}) + \mathbf{92}(O_2(1/P^2/T)$$

Physics

$$Fprob = 1/(\mathbf{-4.3} + \mathbf{1.7x10^{-28}}(A_o \mathbf{e}^{Ea/R\mathbf{T}}) + \mathbf{92}(O_2(1/P^2/T))$$

Standard RATE equations used in the chemistry of combustion

Rate equation for
reaction environment

Reaction rate based on ***present*** temperature and humidity conditions

Rate equation for
reactant concentrations

Reactant concentration rate based on ***past*** temperature and precipitation

physical chemistry rate
$k = A_o \exp^{-Ea/RT}$

+

concentration rate
$r = k[A^x][B^y]$

$$MFI = b_o + b_1 A_o \mathbf{e}^{Ea/R\mathbf{T}} + b_2(O_2(1/P^2/T))$$

Combustion dynamics modeling theory and application

Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335. go to: Tree Search for a high resolution map (Figure 4) you can download.

Guyette, R.P., M.C. Stambaugh, J.M.. Marschall, E. Abadir. 2015. An analytical approach to climate dynamics of fire frequency in the Great Plains. Great Plains Research. Fall

Guyette, R.P., F.R. Thompson, J. Whitter, M.C. Stambaugh, and D.C. Dey. 2014. Future Fire Probability Modeling with Climate Change Data and Physical Chemistry. Forest Science.13-108.

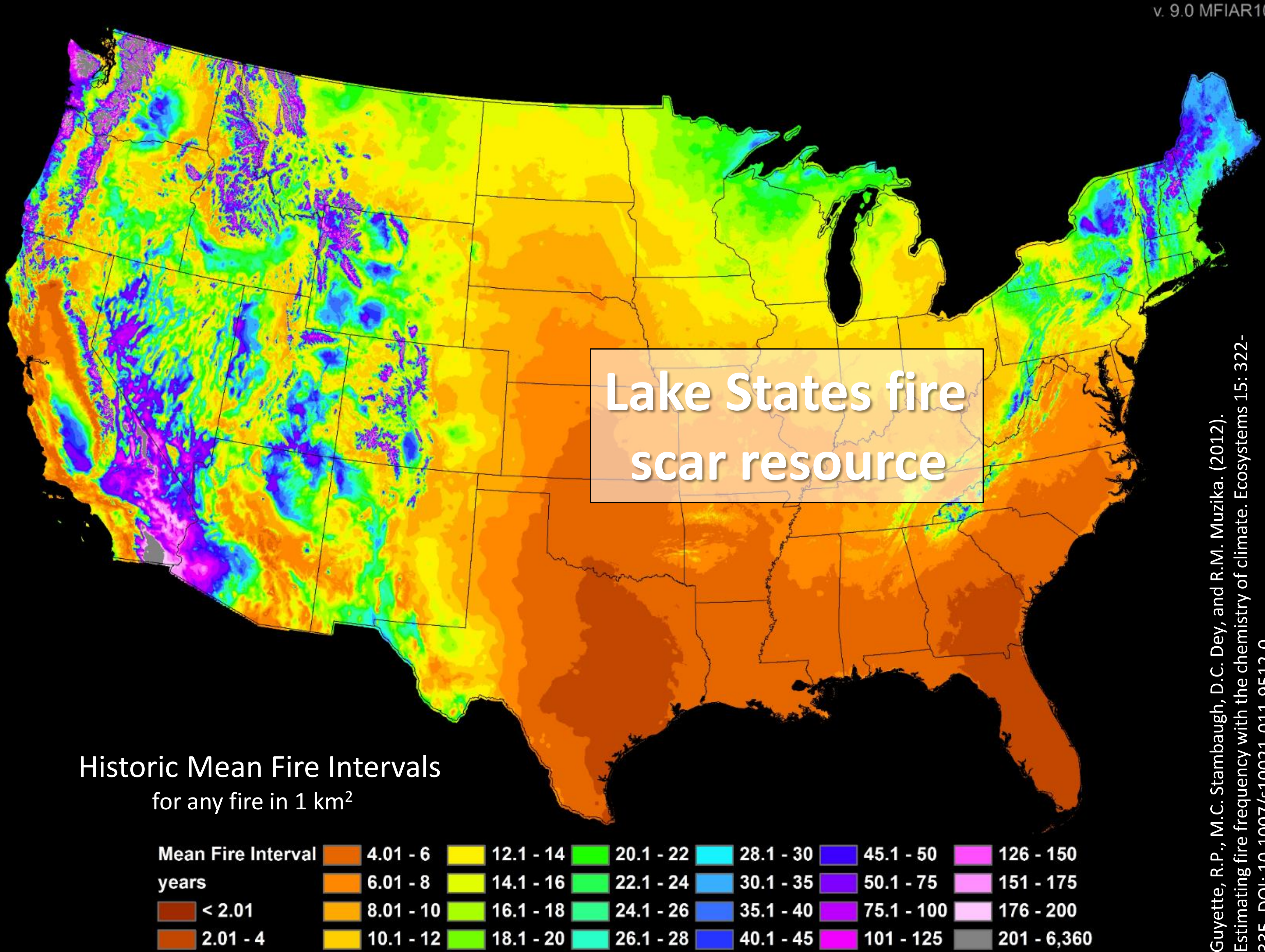
$$MFI = -4.3 + 1.7x10^{-28}(A_o e^{Ea/RT}) + 92(O_2(1/P^2/T))$$

regression calibration & bridging of molecular and ecosystem climate & fire

collision frequency

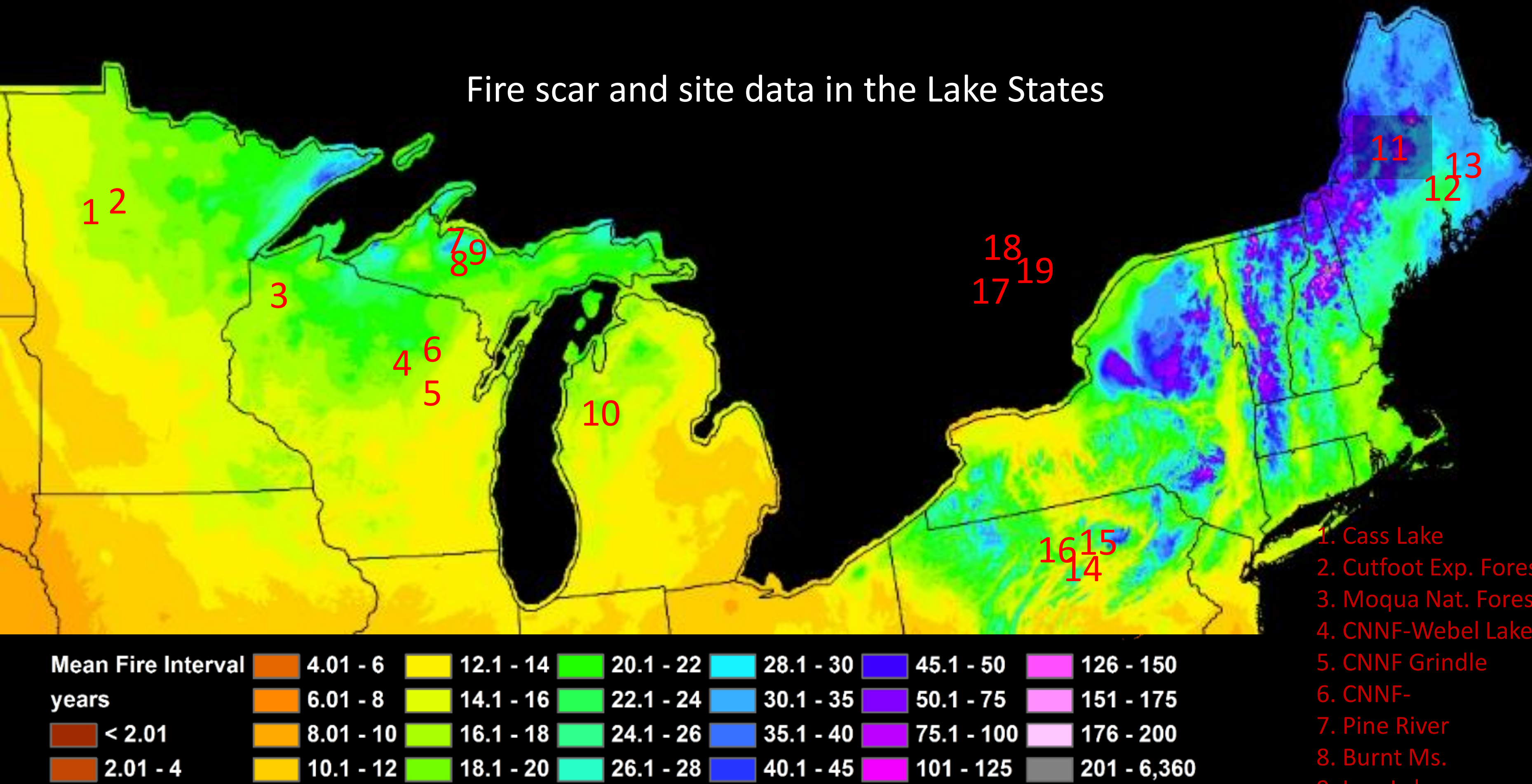
fuel proxy

Lake States fire scar resource



Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335. DOI: 10.1007/s10021-011-9512-0

Fire scar and site data in the Lake States



1. Cass Lake
2. Cutfoot Exp. Forest
3. Moqua Nat. Forest
4. CNNF-Webel Lake
5. CNNF Grindle
6. CNNF-
7. Pine River
8. Burnt Ms.
9. Ives Lake
10. Wolf Lake
11. Joe-Mary Lakes
12. Gassabias Lake
13. 4th Machias Lake
14. Upper Dugan
15. Slate Run
16. Pine Creek
17. Opeongo Lake
18, Basin Lake
19. Algonquin Park

PC2FM with PRISM climate data

Historic Mean Fire Intervals

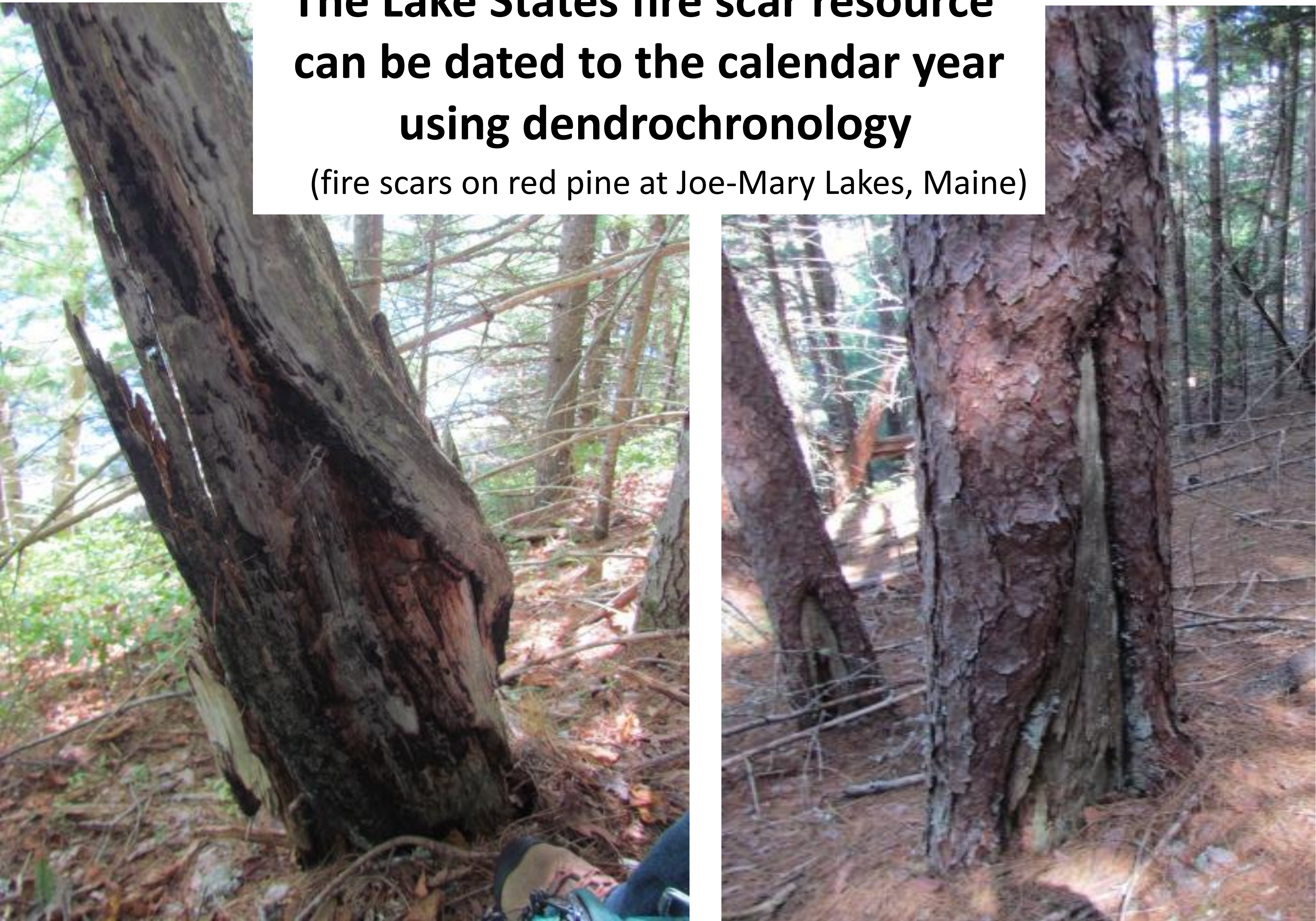
< 1850 for any fire in 1 km^2

Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335. DOI: 10.1007/s10021-011-9512-0


Our data base begins with fire scars on trees growing in many diverse climates from Alaska to Florida. These scars are from fires in the Northeast Sands Ecosystems of Wisconsin

The Lake States fire scar resource can be dated to the calendar year using dendrochronology

(fire scars on red pine at Joe-Mary Lakes, Maine)



Even in very moist climates there are many slow growing trees, stumps, and snags on dryer sites, eskers, dunes, and near bogs that have excellent fire scar records, Gassabias Lake, “Downeast Maine”.

Along short slopes next to bogs where berries and moose feed there are red pine with multiple fire scars. The location, scar direction, and frequency indicate human activity.

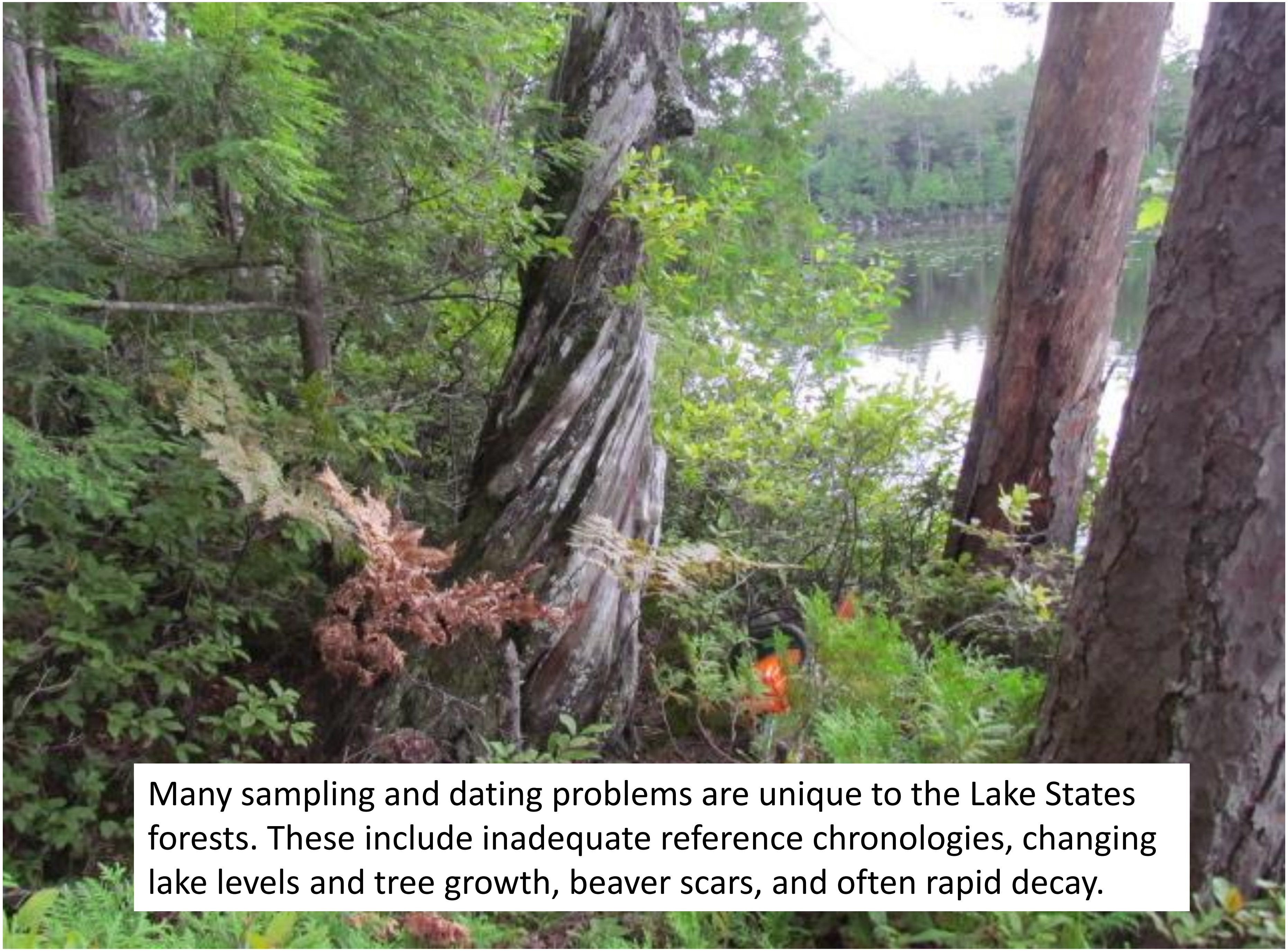
Fire scars in the Adirondack Mountains, New York


Live and dead 300+ year old fire-scarred red pine
on a paleo dune on the south shore of Lake Superior
Red pine is the best, but not the only fire recorded species in the
Lake States because of its resinous wood's resistance to decay.

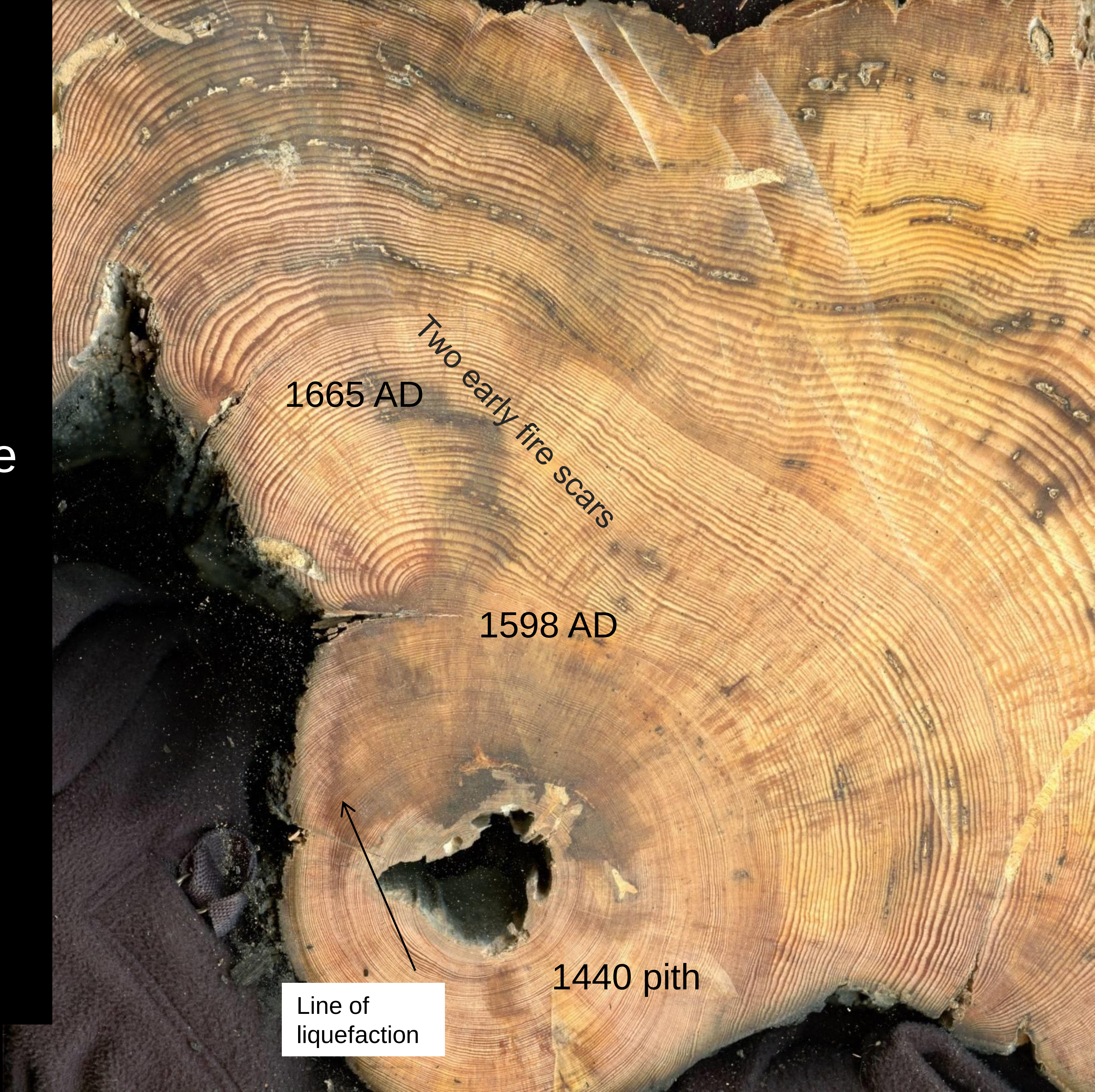
Highly decayed red pine remnant with enough rings for dating and a few fire scars in the Northwest Sands Ecological Landscape of Wisconsin

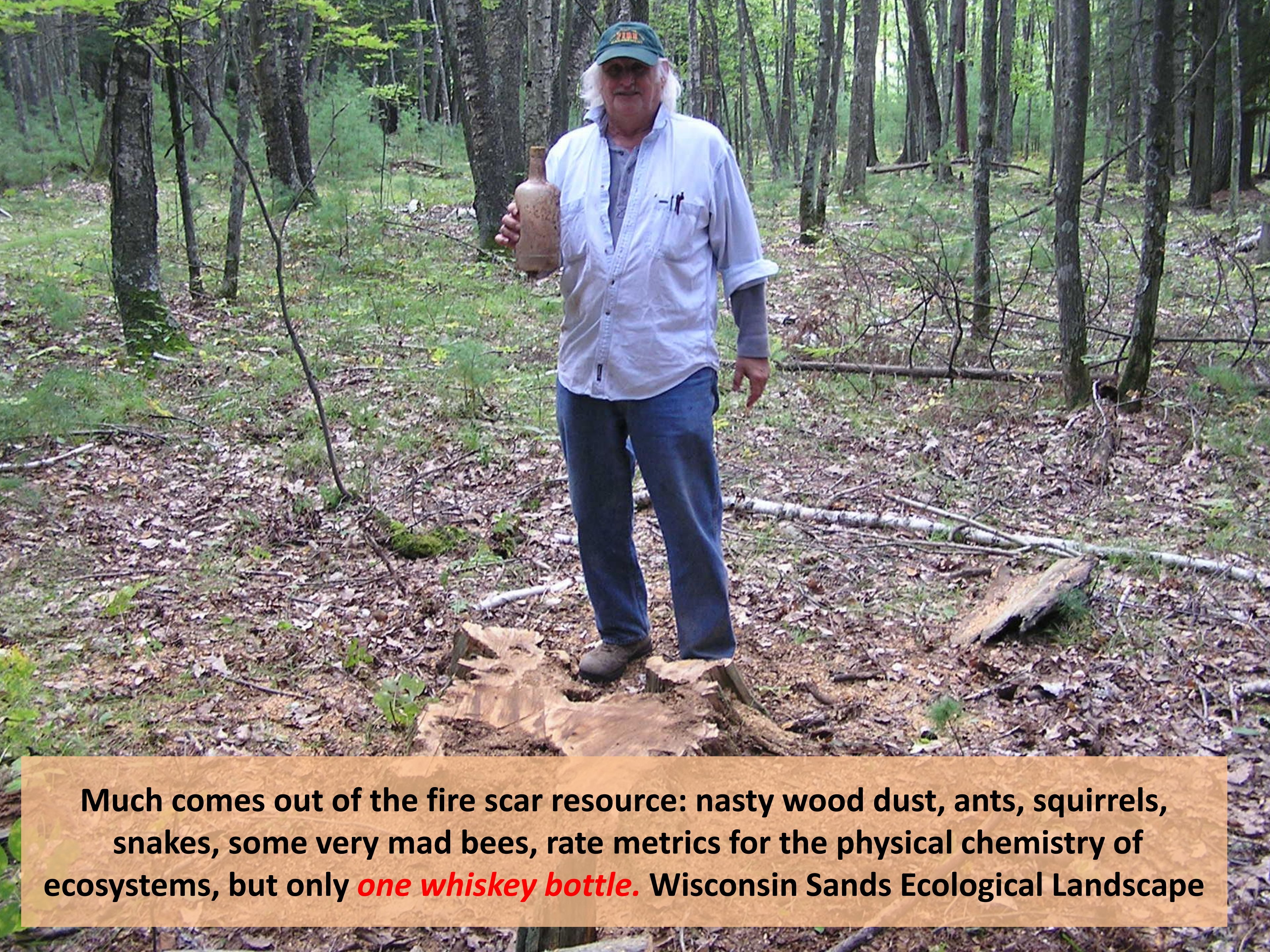
Resinous red pine wood is often preserved with outside ring dates circa 1850 in Michigan, Minnesota, Ontario, Wisconsin, Maine and other states.

These stumps and snags leave a historic record of fire before climate change and industrial forestry, but are decaying, used for starter, and often removed in prescribed fire.


Many sampling and dating problems are unique to the Lake States forests. These include inadequate reference chronologies, changing lake levels and tree growth, beaver scars, and often rapid decay.

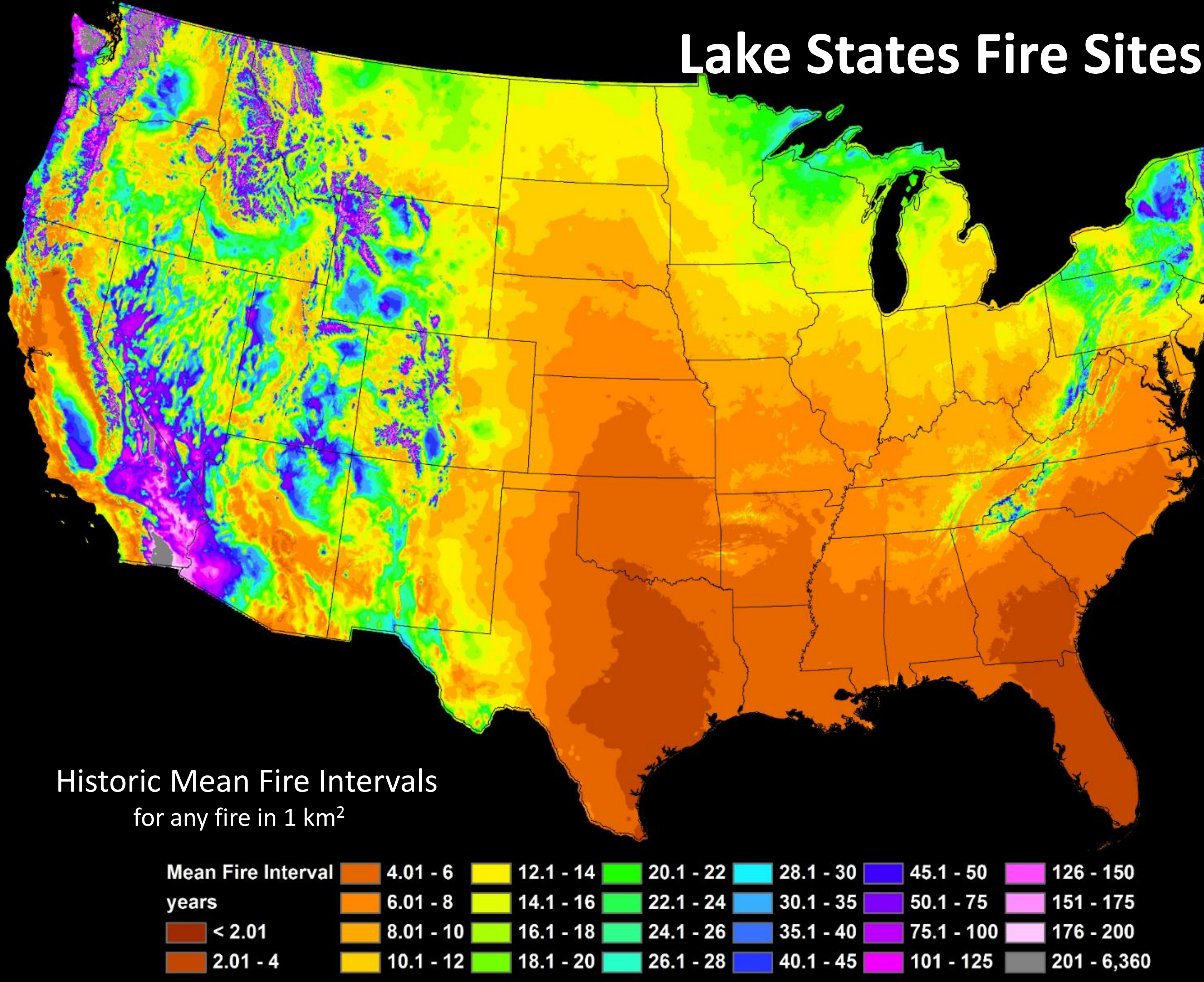
Slow growth, resin, micro climate, and fire heating of the tree bole produced this 354 ring red pine natural remnant in the Huron Mts., Michigan’s UP. These occur in the Northeast, but it takes a lot of field time to find them.





Much comes out of the fire scar resource: nasty wood dust, ants, squirrels, snakes, some very mad bees, rate metrics for the physical chemistry of ecosystems, but only *one whiskey bottle.* Wisconsin Sands Ecological Landscape

Lake States Fire Sites



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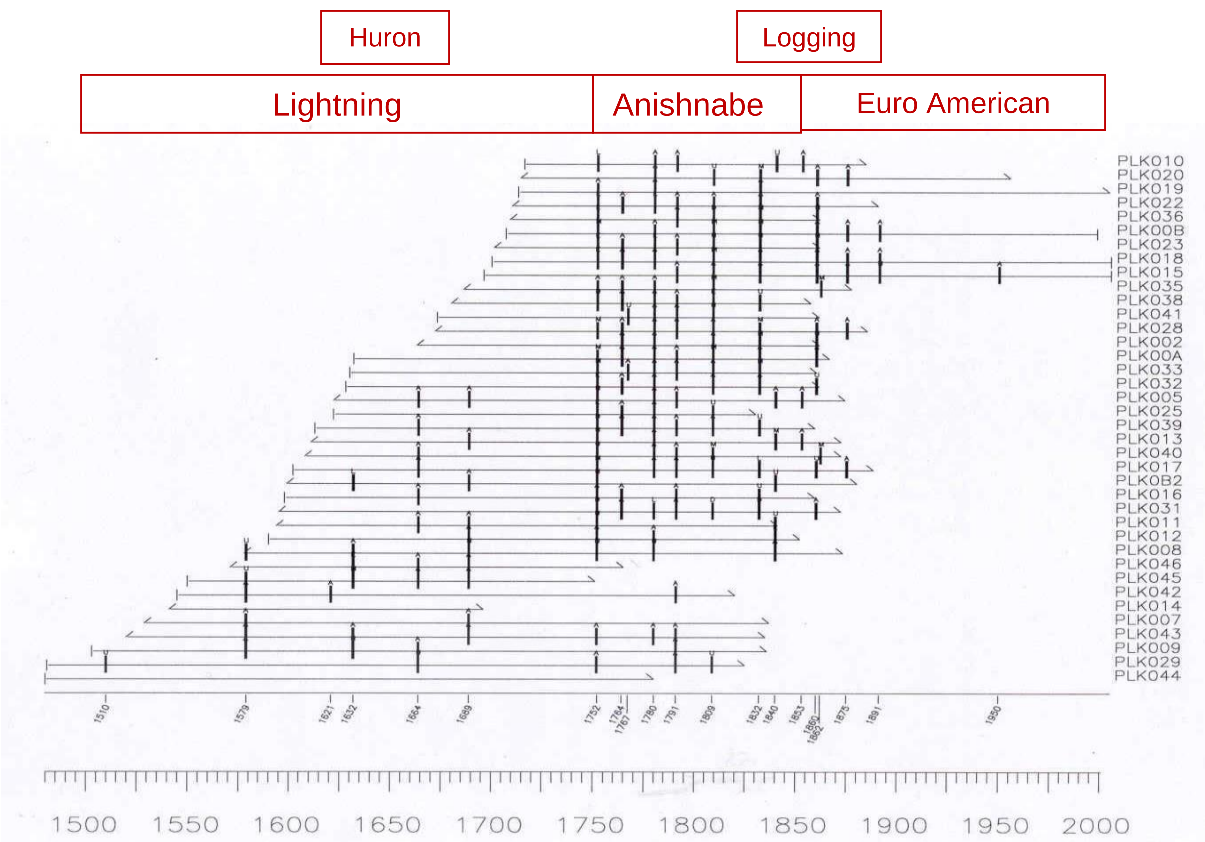
Time & Fire on the shore of Lake Superior, Huron Mts.

Red pine stump, 1632 -1862, 8 scars, MFI = 34 years

Red and Jack Pine



Modeling importance:

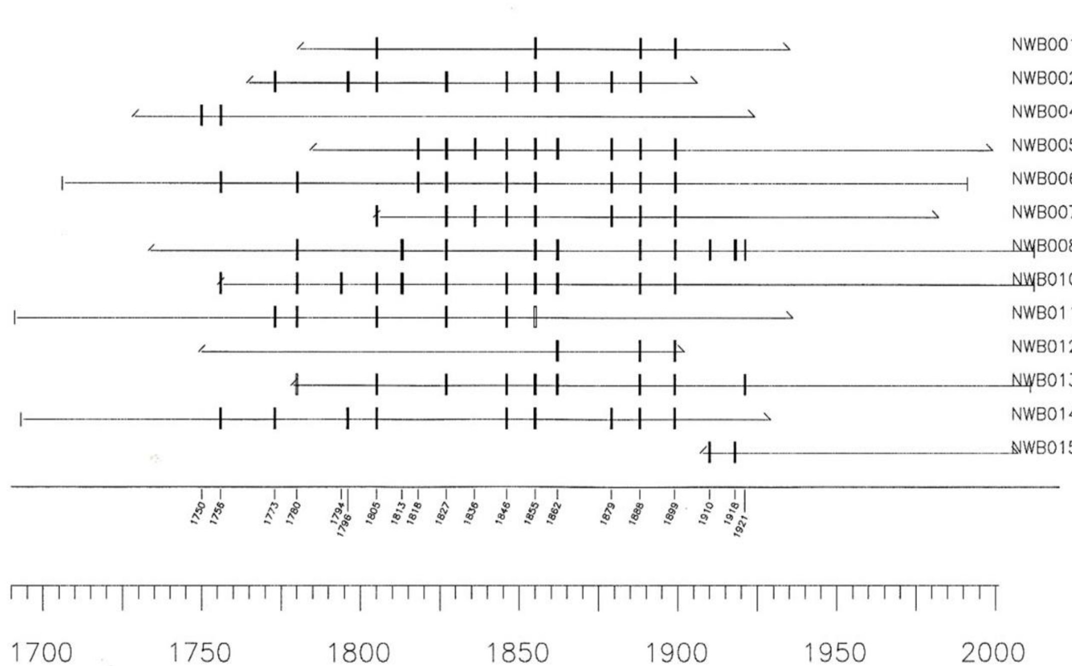
1. Low elevation, cold, deep snow climate
2. Lightning to human fire regimes in 1752
3. Native American burning for blueberries
4. Low elevation land-water interface

Red pine blow down and fire scars, Cass Lake, Chippewa National Forest, Minnesota

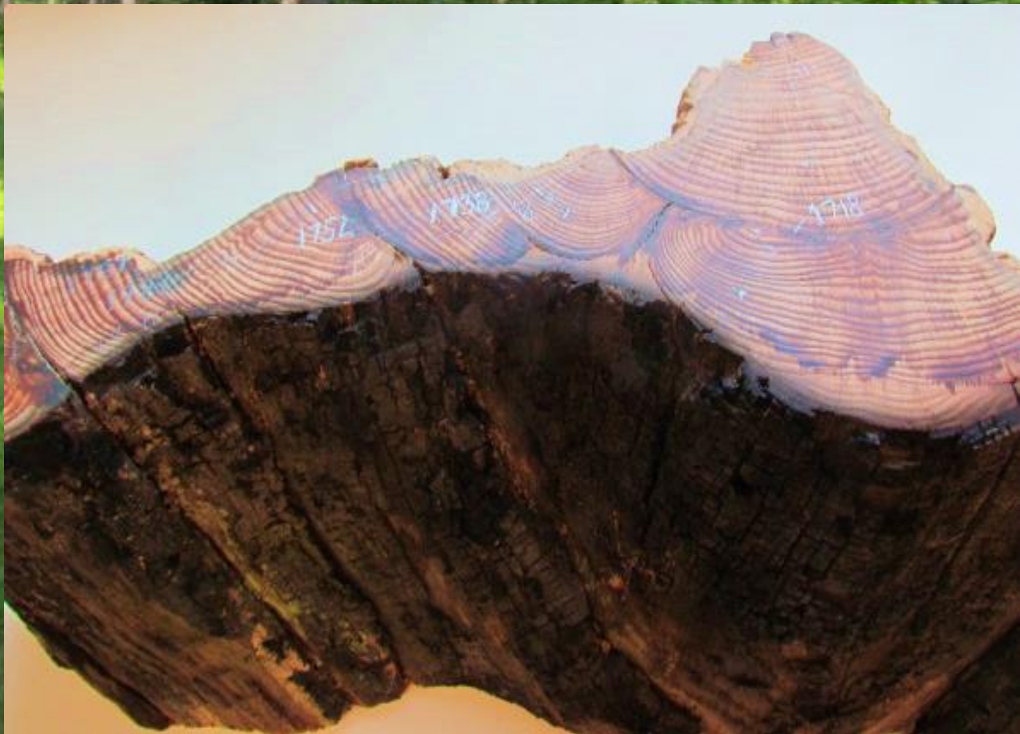
Fire metrics in parts of the Chippewa Nation Forest were the result of climate, weather and the early silvacultural practices of the Leech Lake Band of the Ojibwe around their homes.

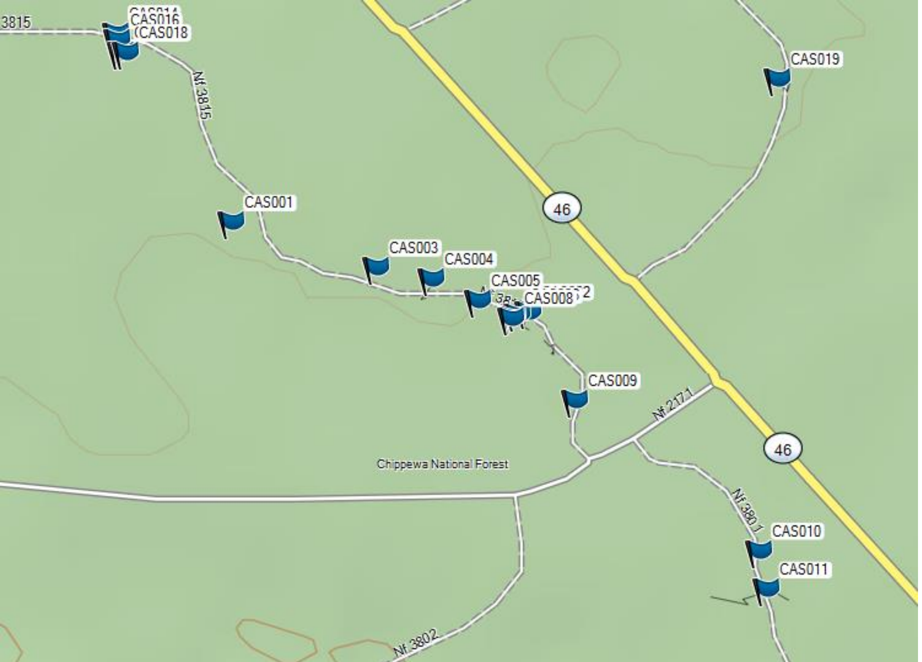
Fire interval statistics for the Norway Beach Site. The row in bold represents the focus period and statistics for the publication.

Calendar dates	Mean fire interval	Median fire interval	Mode	Range	Era Name	One sample runs test for H_o
1690 to 2012	16 years	9.0	9.0	2 to 91	Mixed fire regimes	na
1750 to 1921	**9.0 years**	**9.0 years**	**9.0 years**	**2 to 17 years**	**Native American (Ojibwe)**	**H_a z = 6.1, p < 0.01**
1690 to 1750	> 50 years	na	na	> 50	Low population	na
1921 to 2012	> 91 years	na	na	> 91	Federal suppression	na

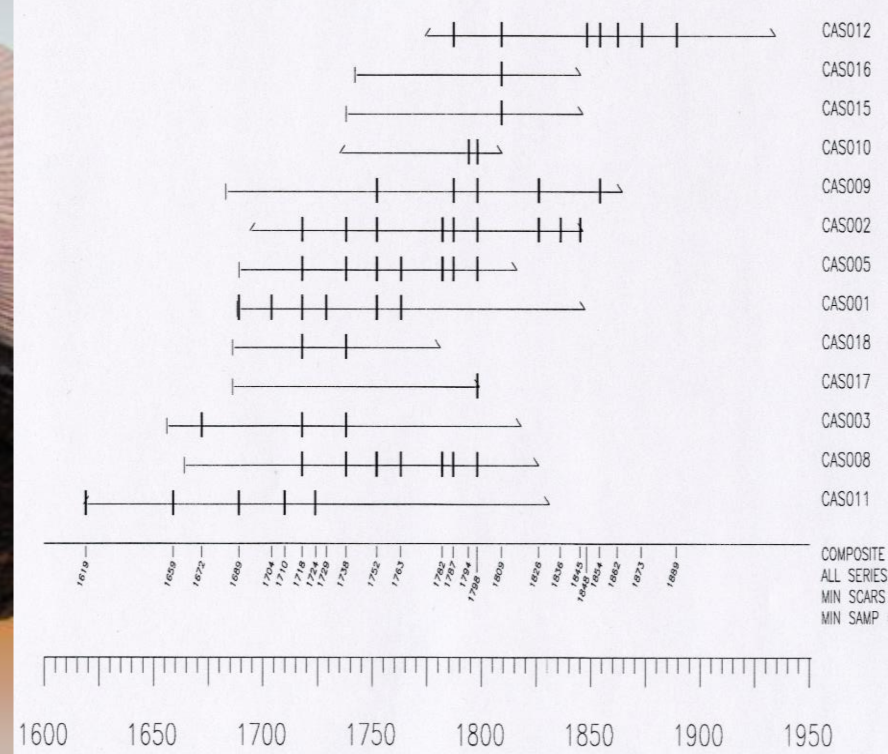


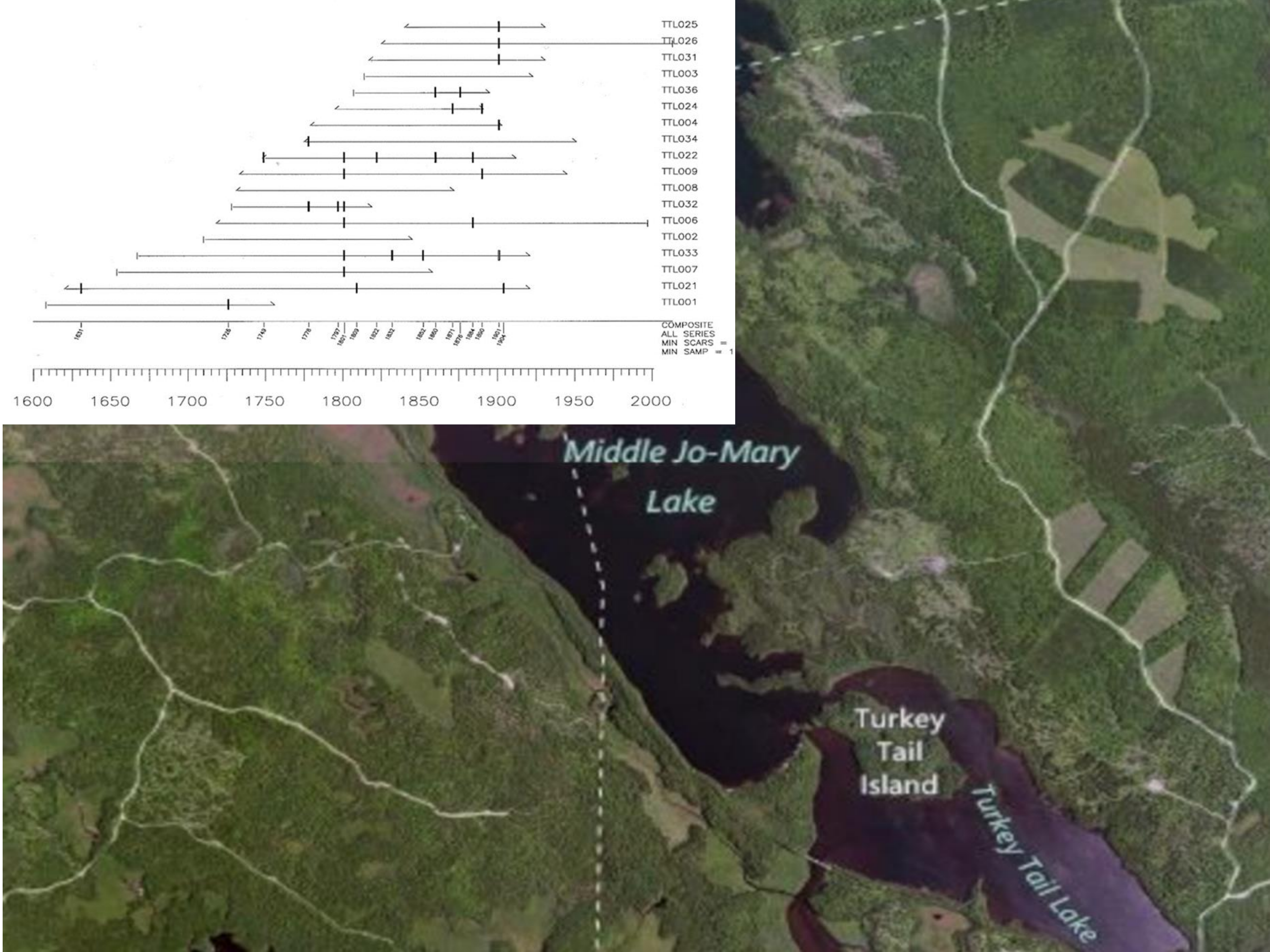
Pre 1860s fire scar record from stumps under the present managed red pines of the Cutfoot Experimental Forest, Minnesota





Fire scar record from dated red pine stumps in the Cutfoot Experimental Forest near Grand Rapids, Minnesota. The site is about 40 km north east of the center of Cass Lake, center of Ojibwe Reservation and Chippewa NF.



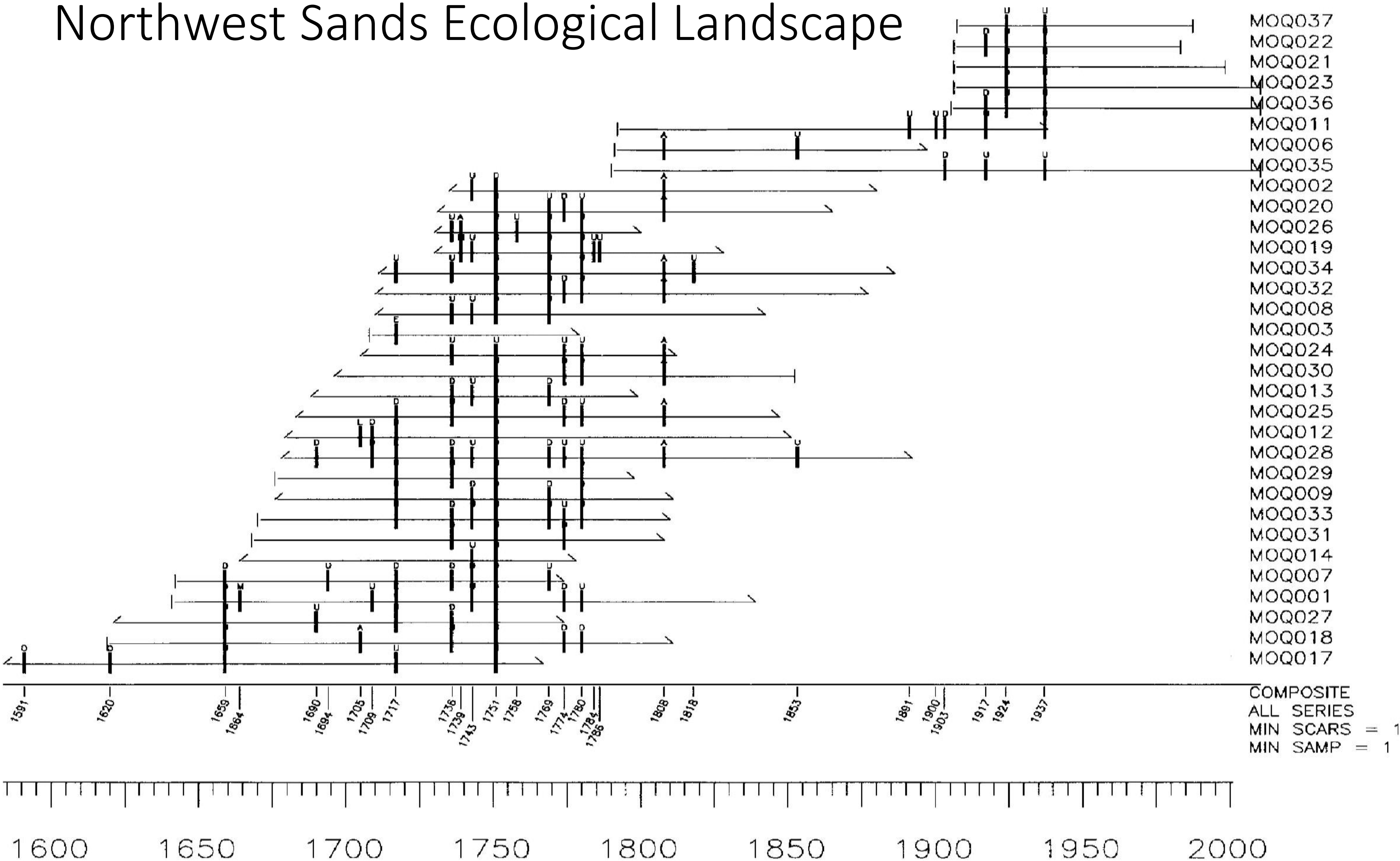

TTL025
TTL026
TTL031
TTL003
TTL036
TTL024
TTL004
TTL034
TTL022
TTL009
TTL008
TTL032
TTL006
TTL002
TTL033
TTL007
TTL021
TTL001
COMPOSITE
ALL SERIES
MIN SCARS =
MIN SAMP = 1
1631
1726
1749
1776
1797
1801
1809
1822
1832
1852
1860
1871
1876
1884
1890
1901
1904
1600
1650
1700
1750
1800
1850
1900
1950
2000
Middle Jo-Mary
Lake
Turkey
Tail
Island
Turkey Tail Lake

Dated fire scars near Gassabias Lake in 'Downeast' Maine.

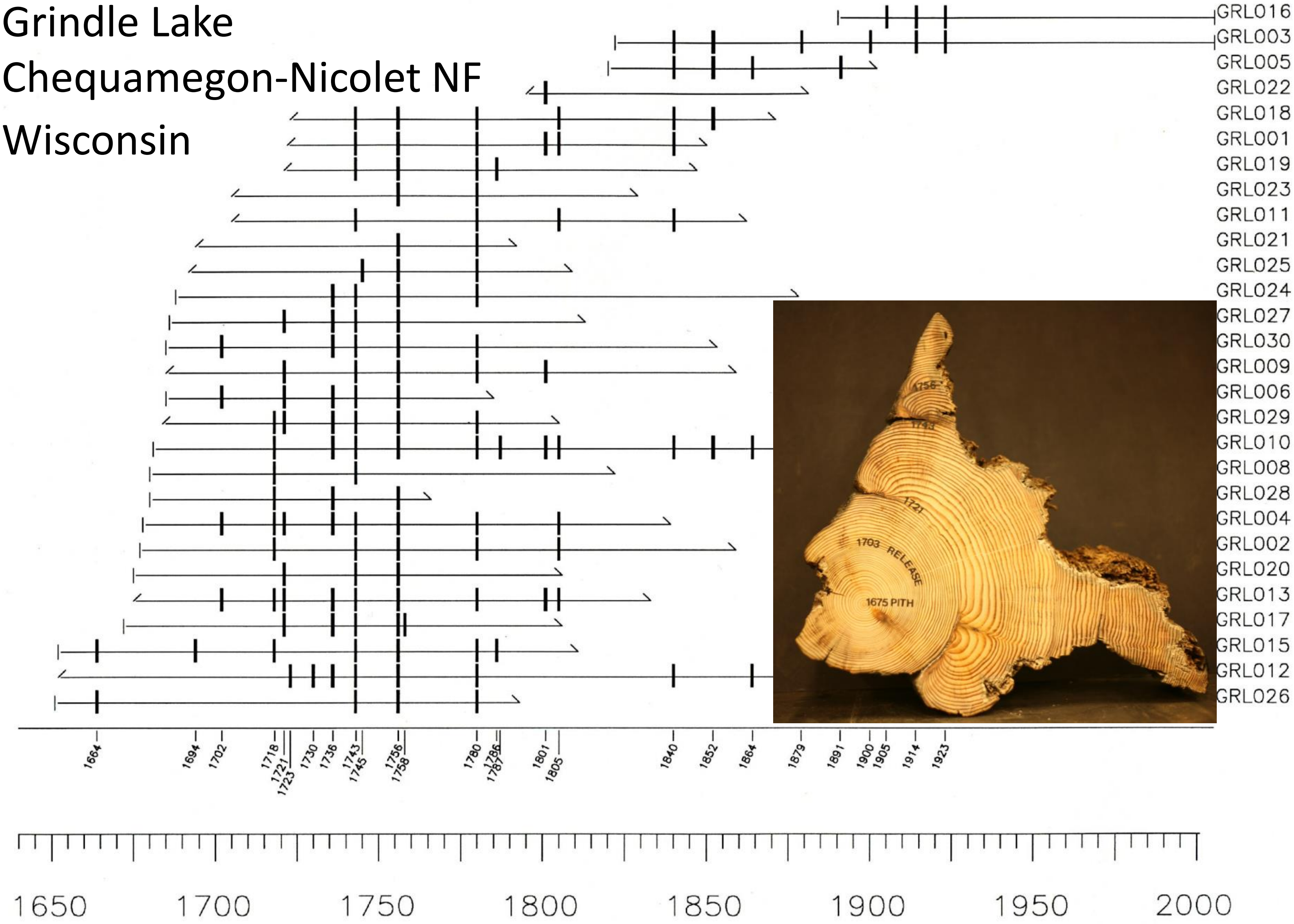
The rate of fire at this 'edge of bog' site may reflect burning for wildlife and berries.

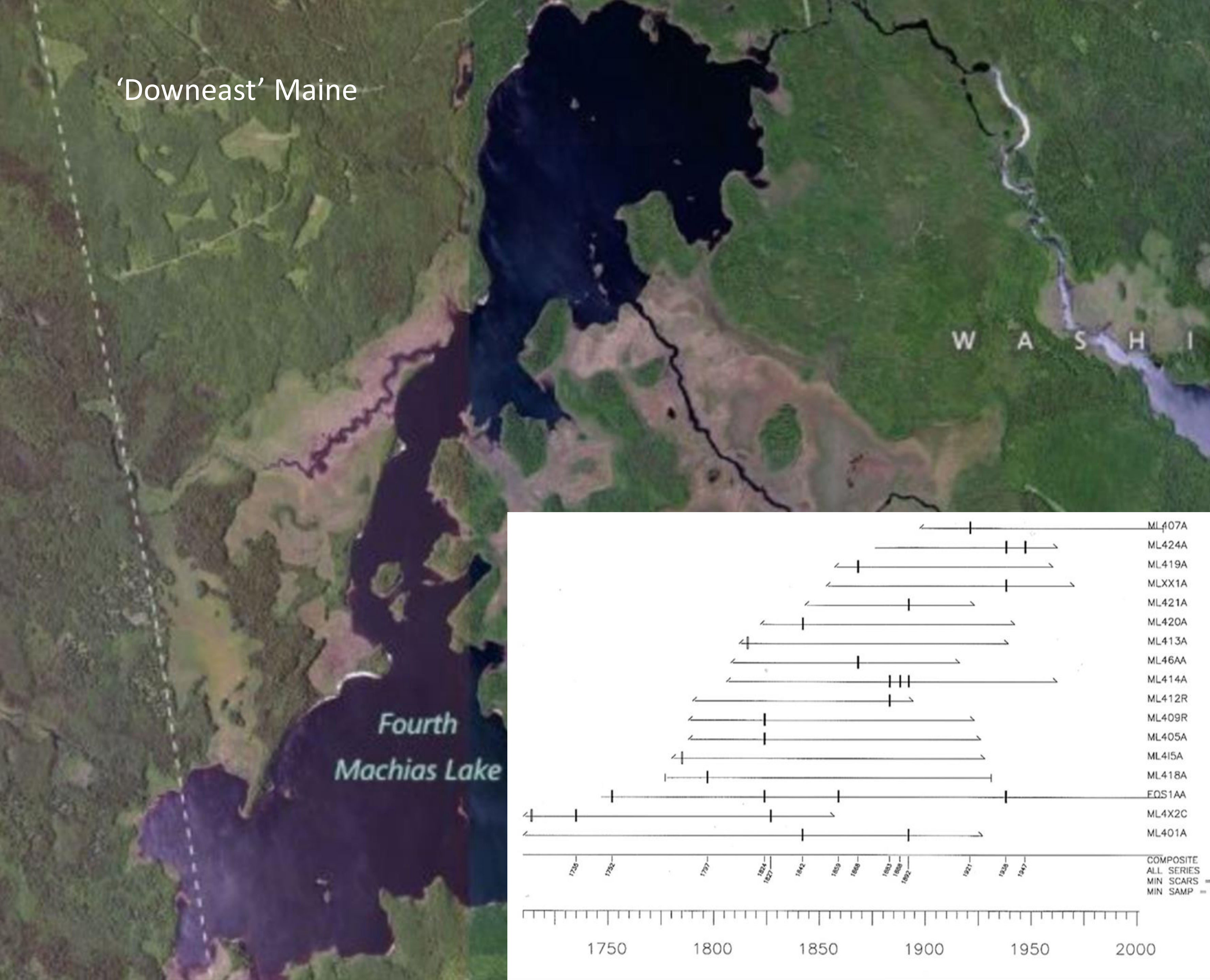
The record of scars that are caused by human purposeful ignition often reflect sporadic human migration. Site south of Passamaquoddy Territory

Moquah Barrens in the Northwest Sands Ecological Landscape



Grindle Lake
Chequamegon-Nicolet NF
Wisconsin



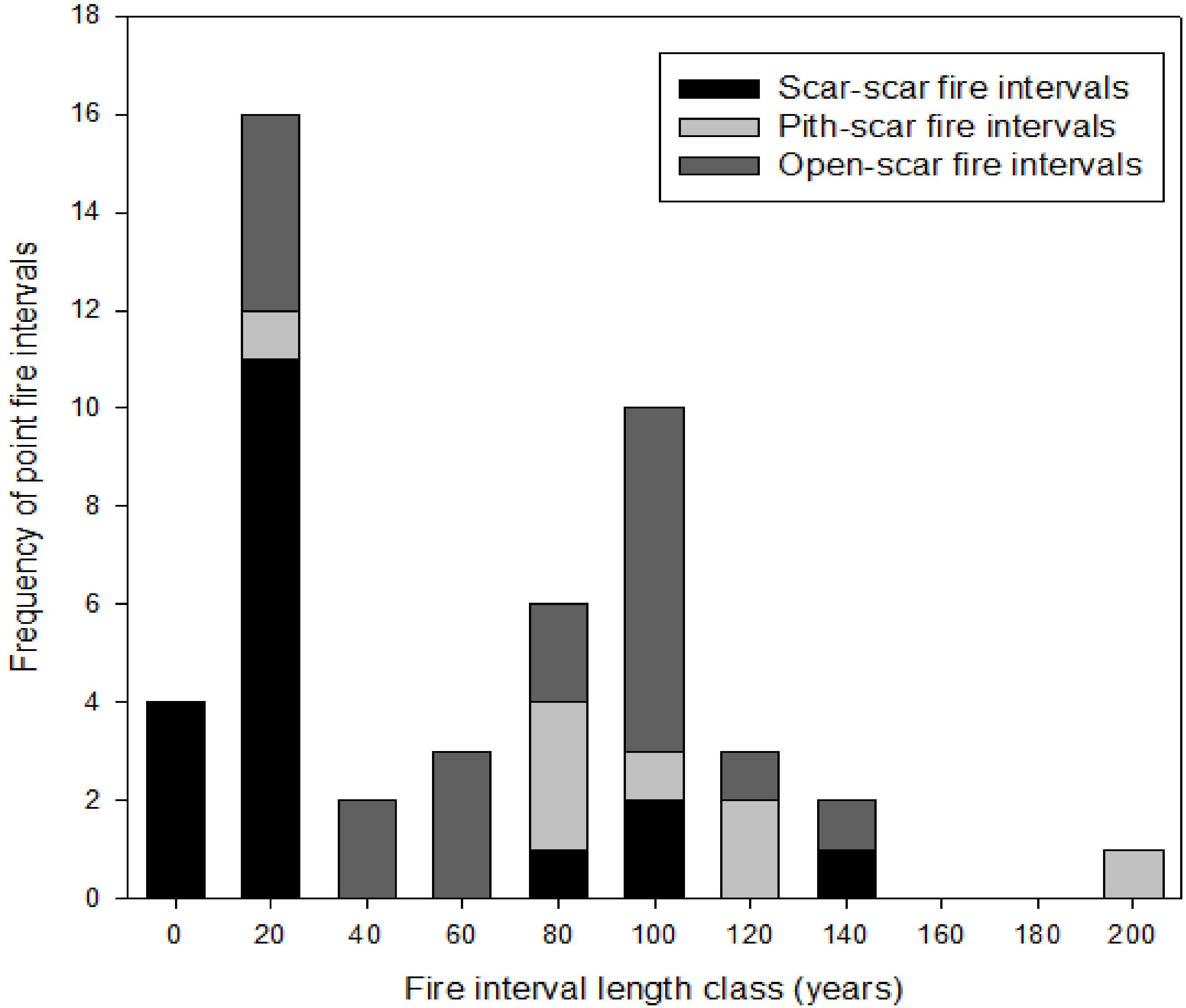


'Downeast' Maine
W A S H I
Fourth
Machias Lake
ML407A
ML424A
ML419A
MLXX1A
ML421A
ML420A
ML413A
ML46AA
ML414A
ML412R
ML409R
ML405A
ML4I5A
ML418A
FOS1AA
ML4X2C
ML401A
1735
1752
1797
1824
1827
1842
1859
1868
1883
1888
1892
1921
1938
1947
COMPOSITE
ALL SERIES
MIN SCARS =
MIN SAMP = 1
1750
1800
1850
1900
1950
2000

Fire scars on dated cross sections are the data base for fire probability rate metrics in ecosystems

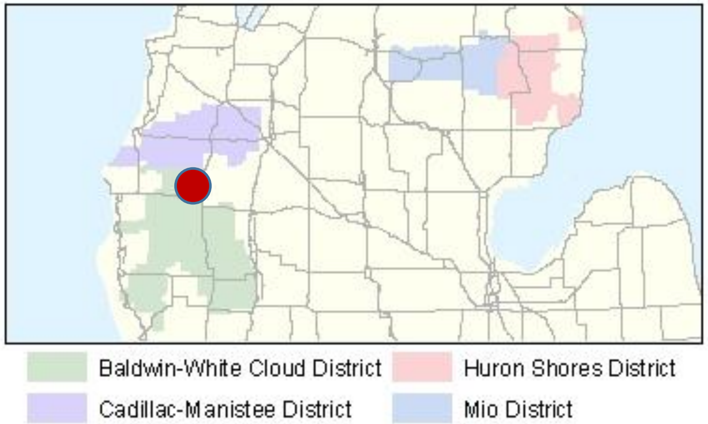
Sandy Stream Road north of Lake Millinocket, Maine

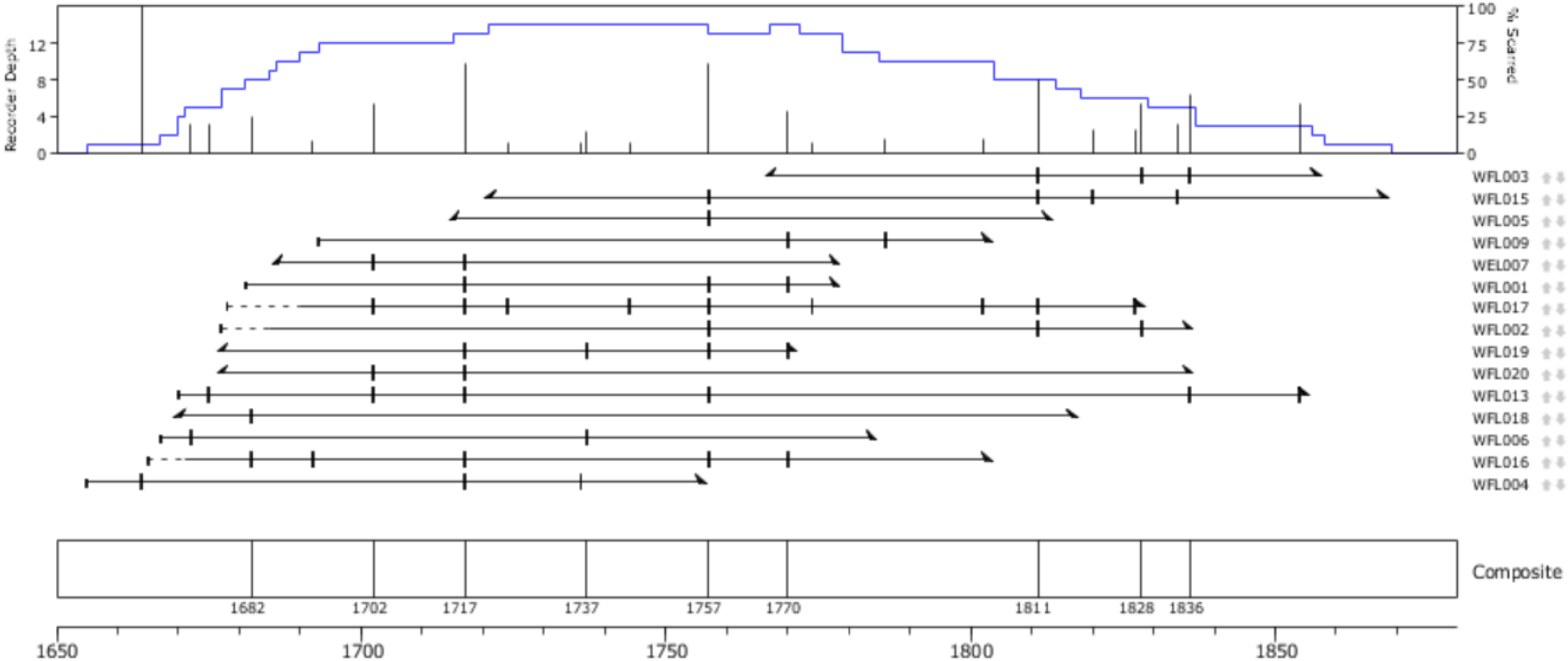
Landscape position has a huge effect on whether ignitions spread into a site



Wolf Lake,
Manistee NF
Lower peninsula,
Michigan
1689 to 1811,
6 fire scars
MFI 20 yrs

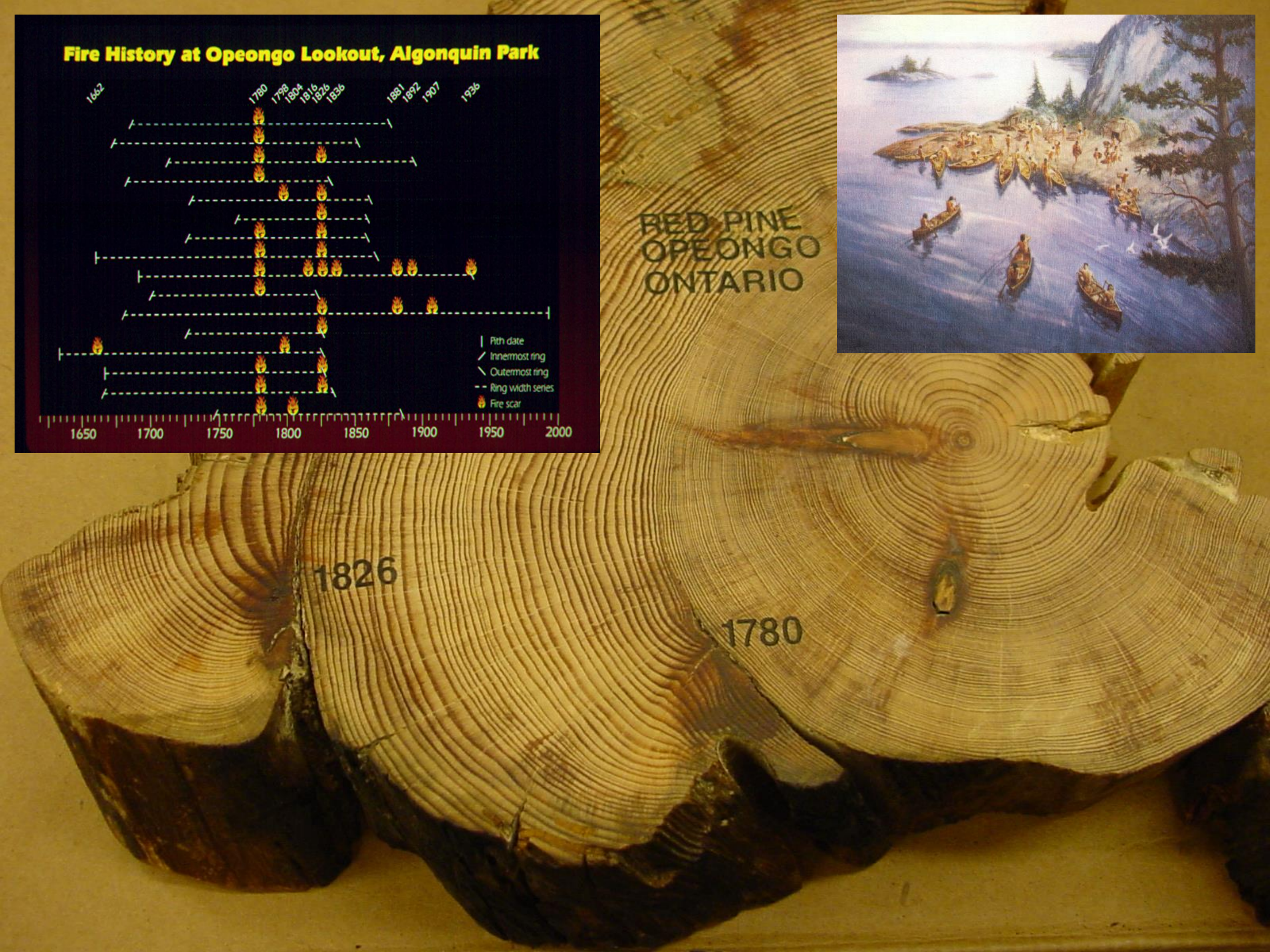
Wolf Lake Site on Manistee National Forest, Baldwin District. The composite mean fire interval for the site, composed of fire years with more than one scar is 22 years. A single tree (WLF017) had 9 scars (MFI `16 years) and grew atop a large SW facing forest opening. Large fires in 1717 and 1757 scarred 66% of the live red pine trees.

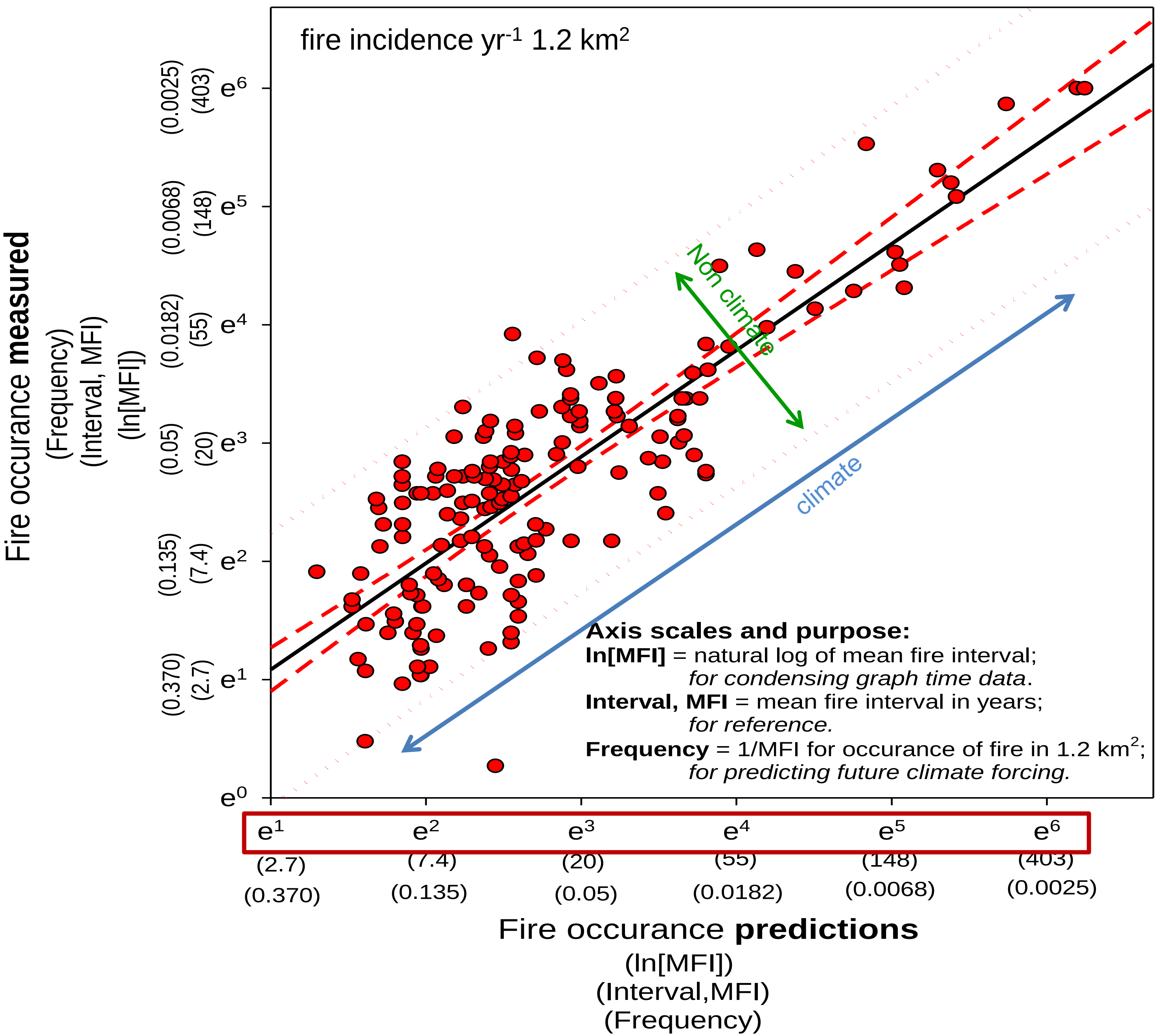




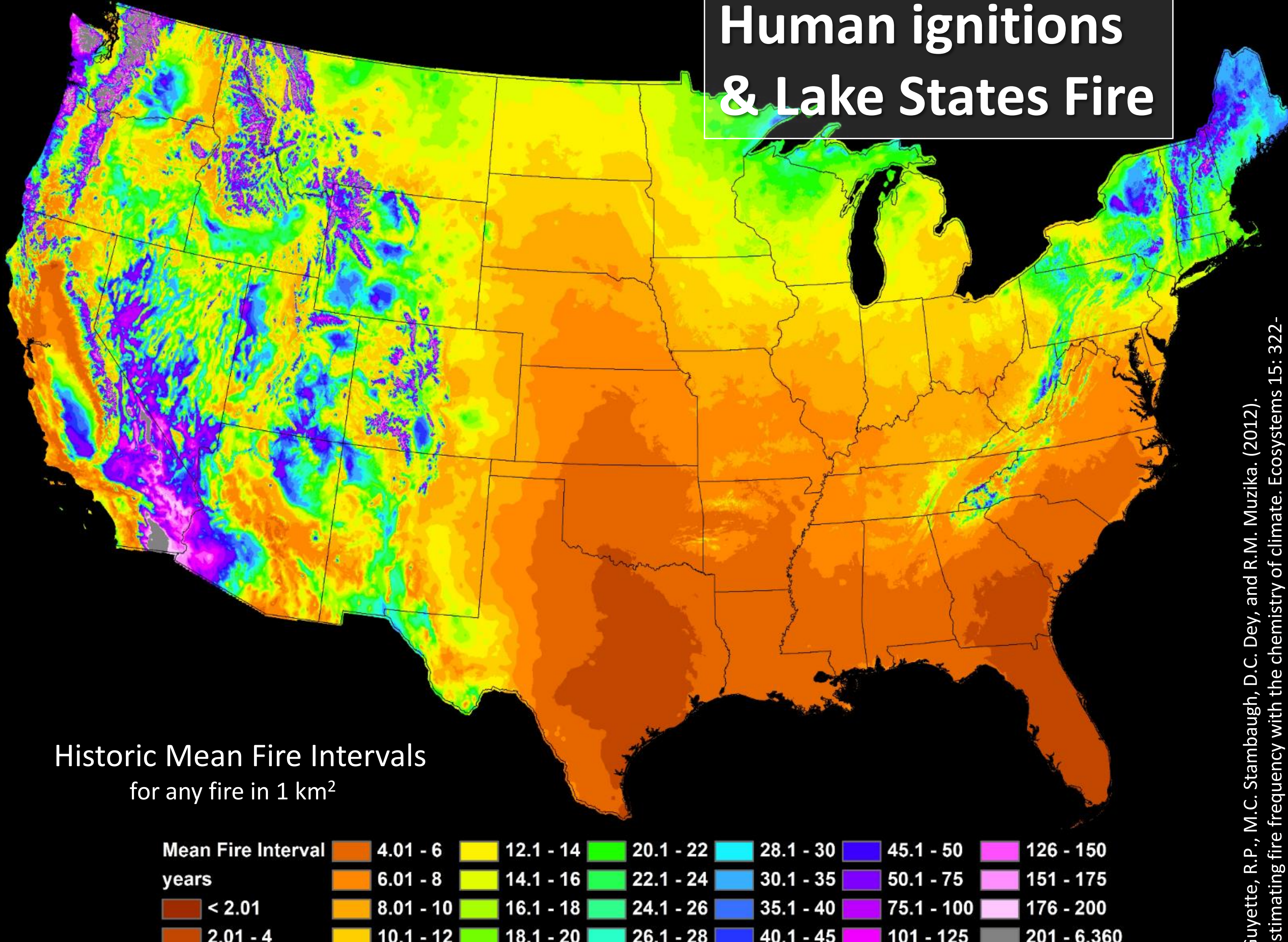

Wolf Lake site,
Manistee NF


MFI ~ 22 yrs
MFI ~ 16 yrs


Fire History at Opeongo Lookout, Algonquin Park
1662
1780
1798
1804
1816
1826
1836
1881
1892
1907
1936
Pith date
Innermost ring
Outermost ring
Ring width series
Fire scar
1650
1700
1750
1800
1850
1900
1950
2000
RED PINE
OPEONGO
ONTARIO
1826
1780


fire incidence yr-1 1.2 km2
Fire occurance measured
(Frequency)
(Interval, MFI)
(ln[MFI])
(0.0025) (403) e6
(0.0068) (148) e5
(0.0182) (55) e4
(0.05) (20) e3
(0.135) (7.4) e2
(0.370) (2.7) e1
e0
Non climate
climate
Axis scales and purpose:
ln[MFI] = natural log of mean fire interval;
for condensing graph time data.
Interval, MFI = mean fire interval in years;
for reference.
Frequency = 1/MFI for occurance of fire in 1.2 km2;
for predicting future climate forcing.
e1 (2.7) (0.370)
e2 (7.4) (0.135)
e3 (20) (0.05)
e4 (55) (0.0182)
e5 (148) (0.0068)
e6 (403) (0.0025)
Fire occurance predictions
(ln[MFI])
(Interval,MFI)
(Frequency)

Human ignitions & Lake States Fire



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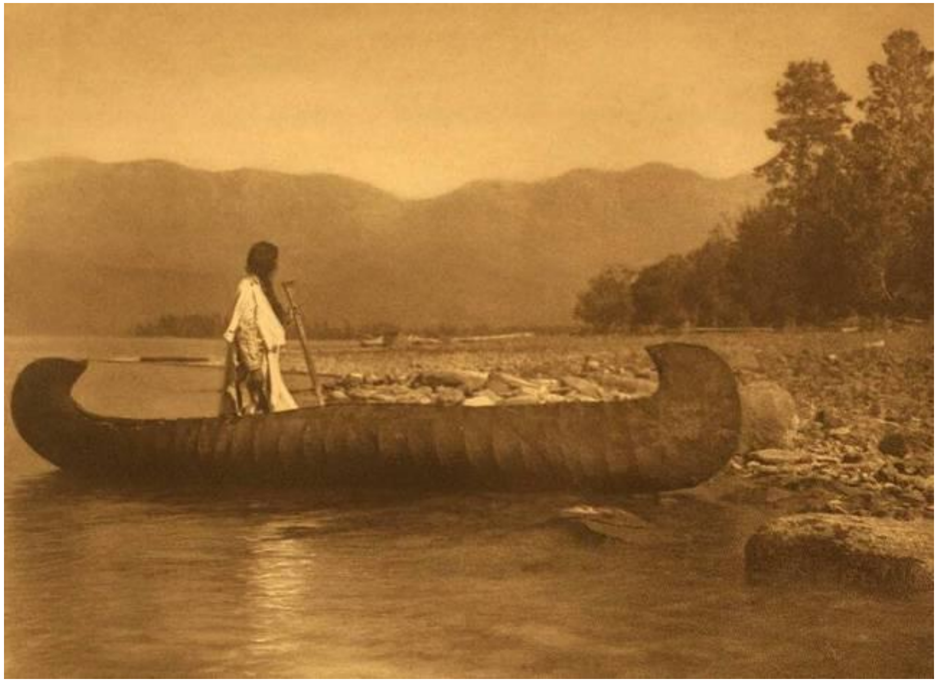
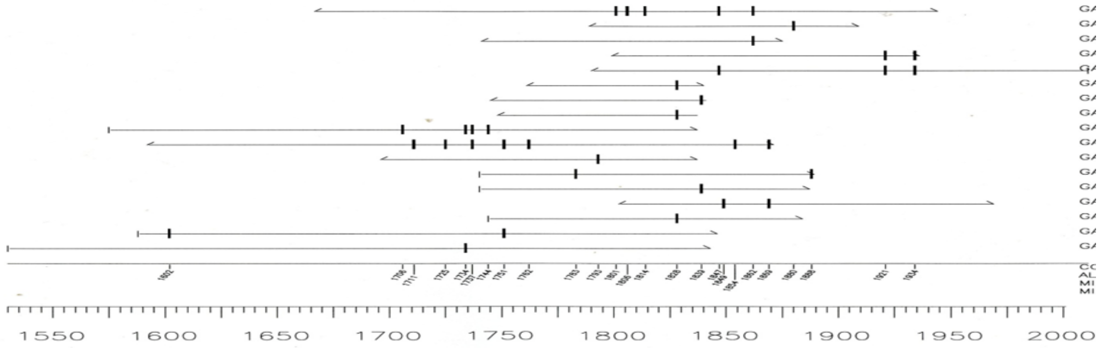
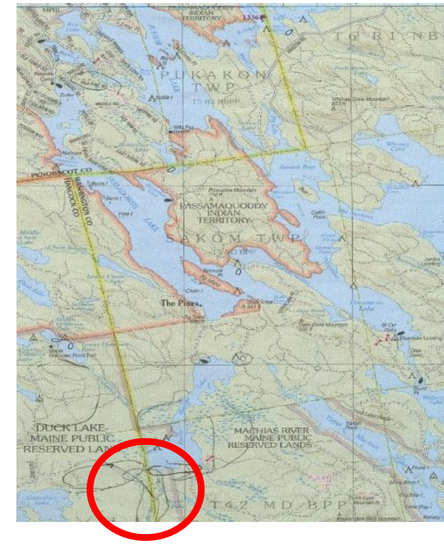
Carbon based exothermic reactions require activation energy (a spark or match) to begin the release of heat by breaking carbon bonds. Humans are by far the most 'fire obligate species' on the planet and they are very capable of 'smart ignitions'.

Trying to understand ecosystem fire without the history of this specie's use of activation energy is like setting up a chemistry bench without a Bunsen Burner or excluding humans in fire ecology because they are not 'natural'.

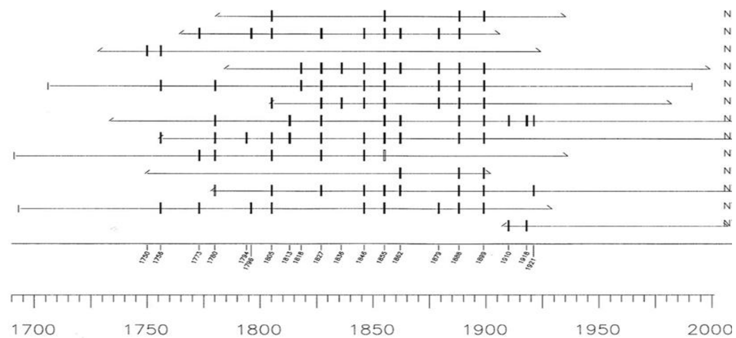


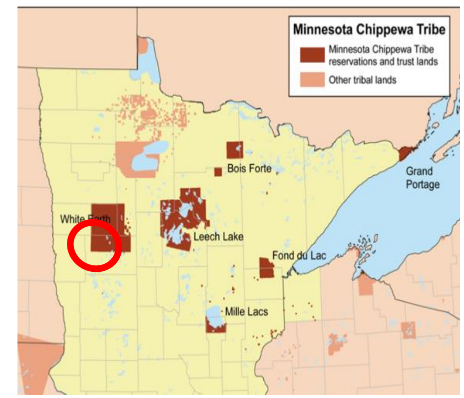
Passamaquoddy, Grand Lake Stream, Maine



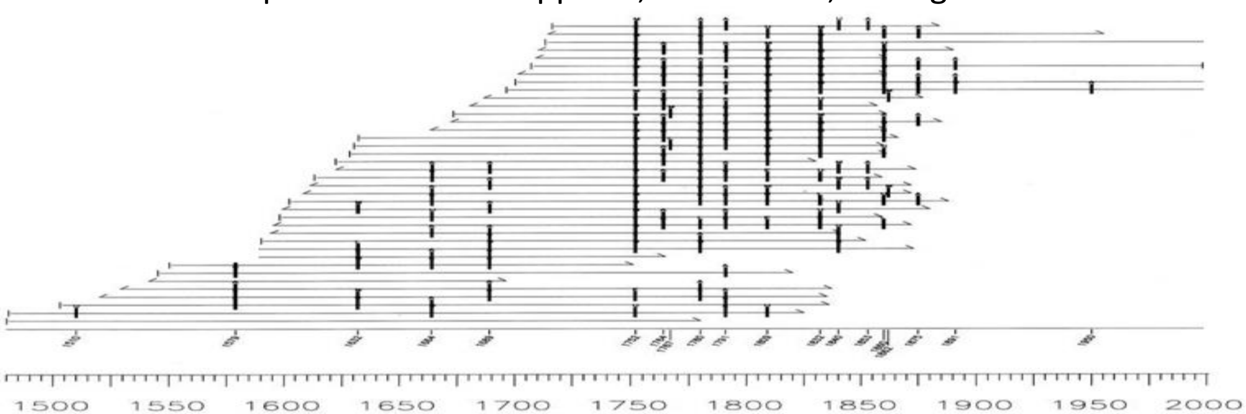


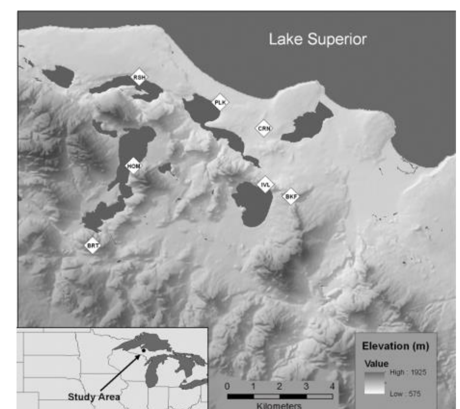
Leech Lake Band of the Ojibwa, Cass Lake, Minnesota



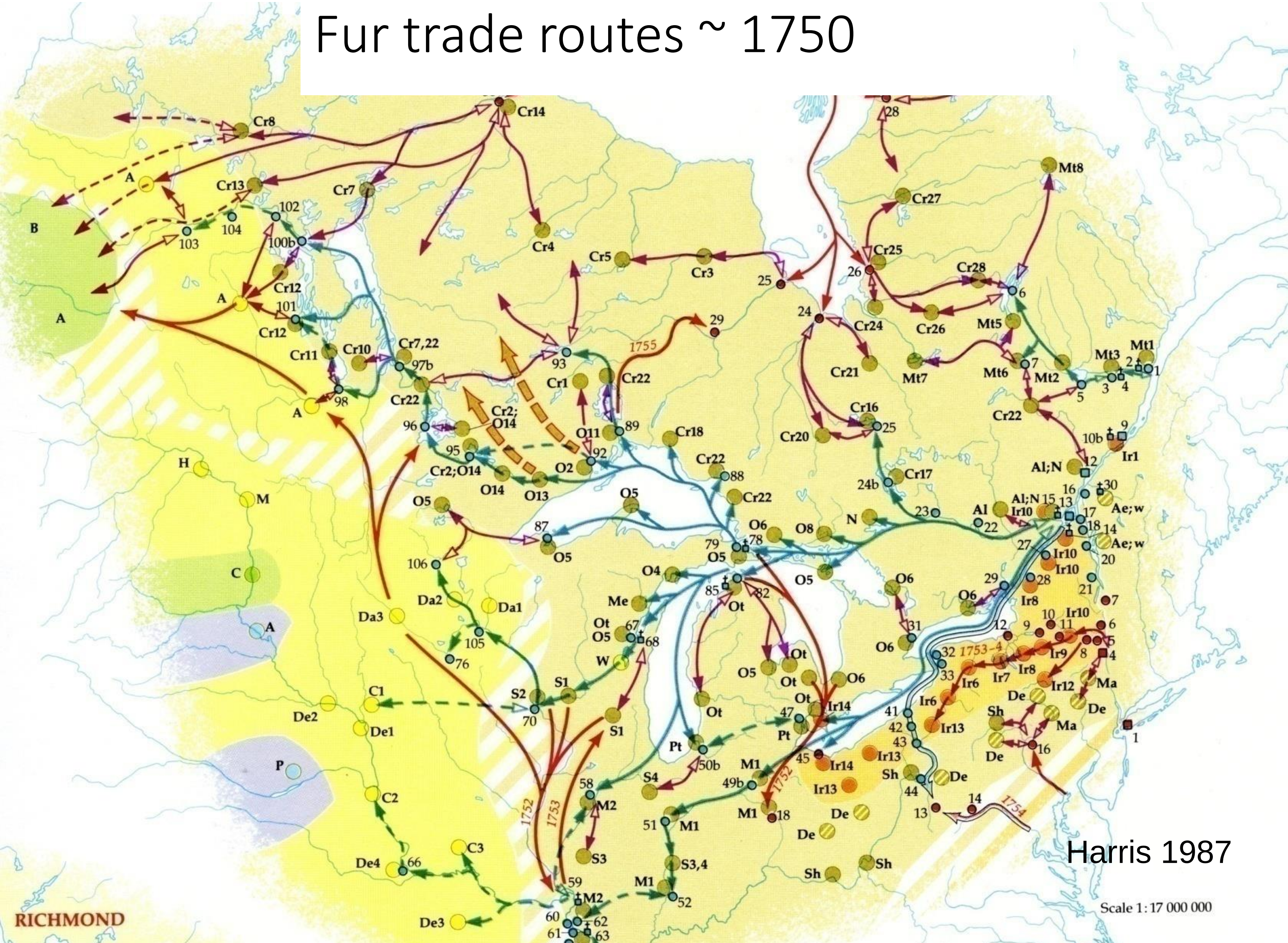


Lake Superior Band of Chippewa, Huron Mts., Michigan



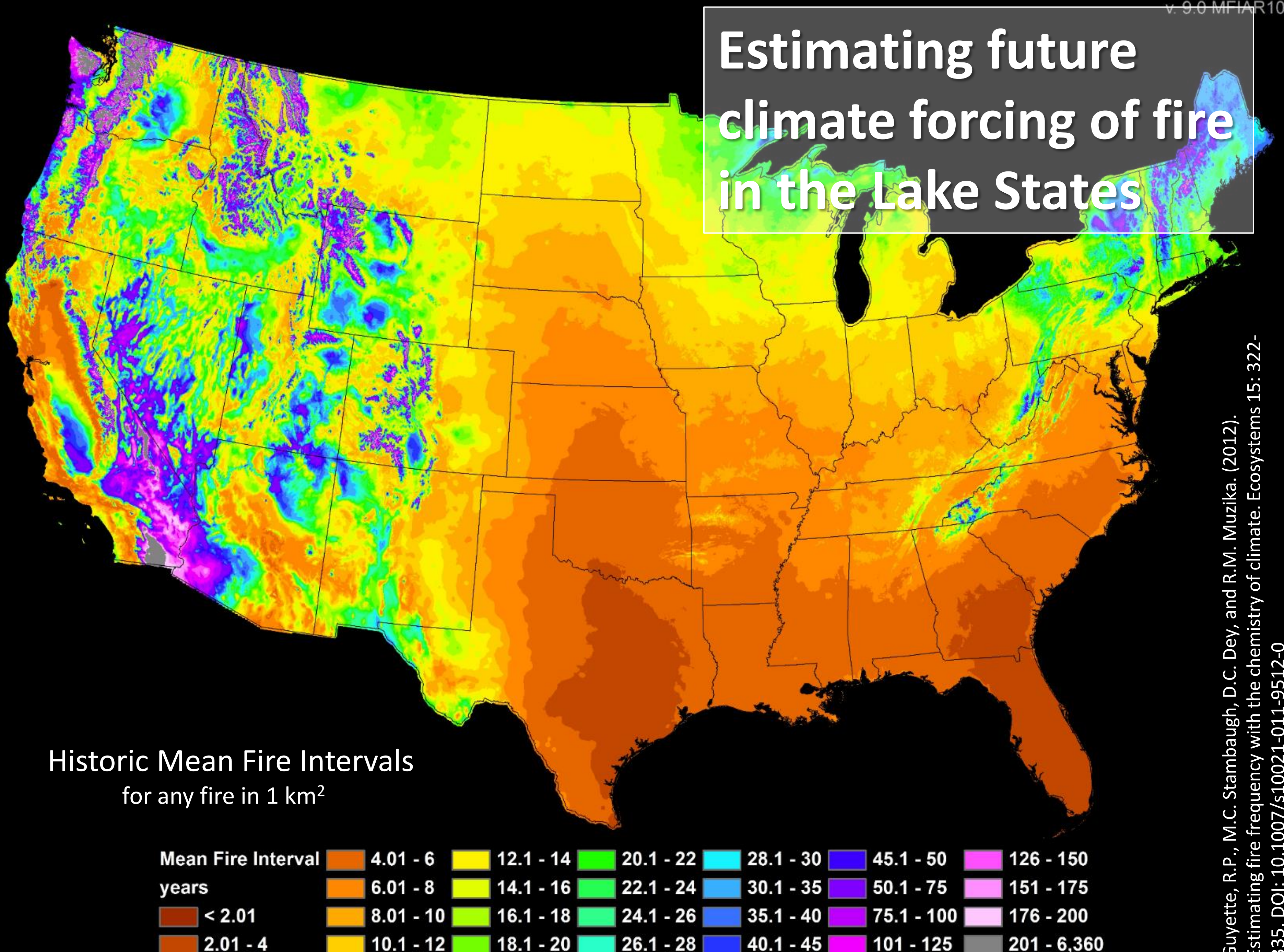


Fur trade routes ~ 1750



Harris 1987

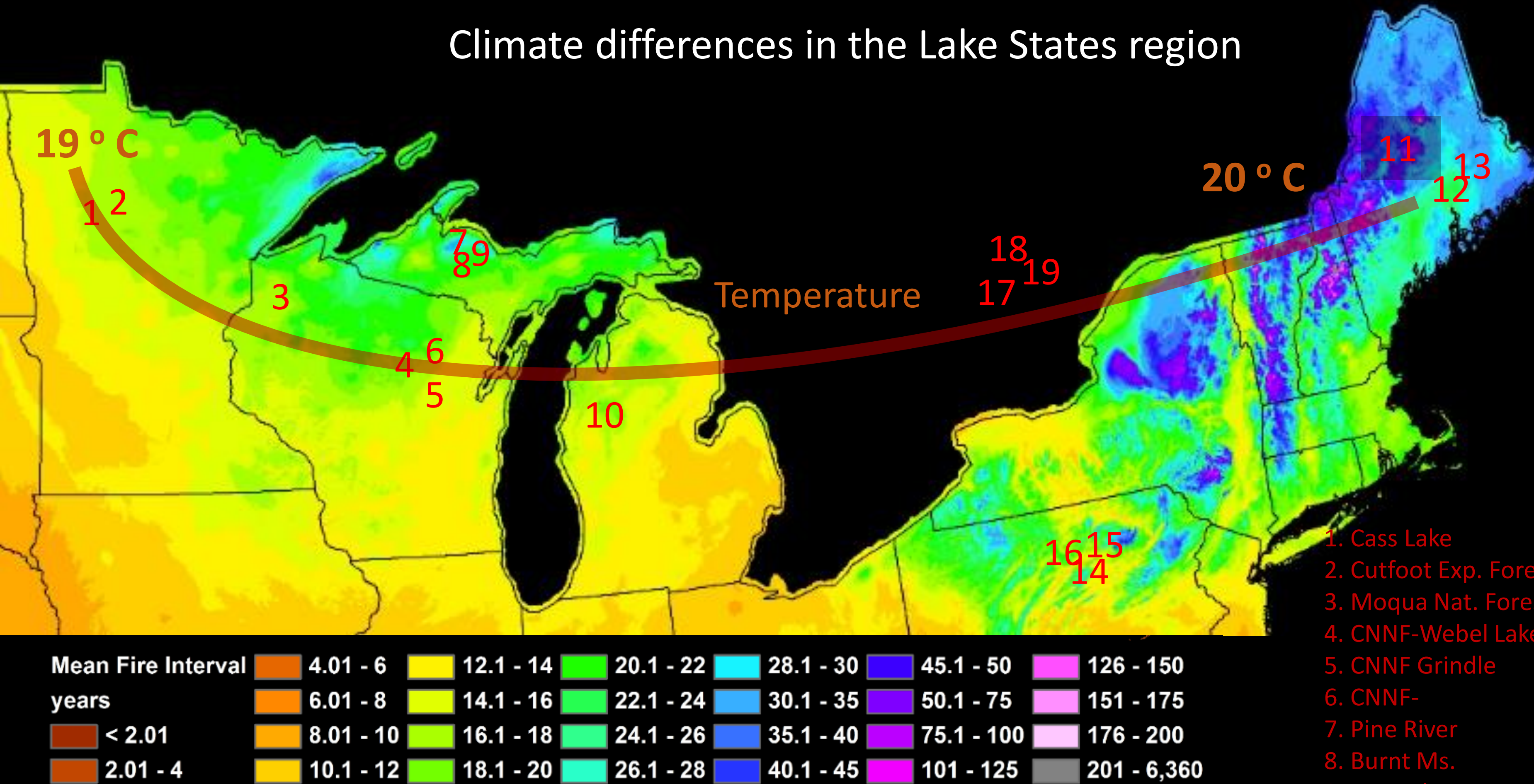
Estimating future climate forcing of fire in the Lake States



Historic Mean Fire Intervals
for any fire in 1 km^2

Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335. DOI: 10.1007/s10021-011-9512-0

Climate differences in the Lake States region



1. Cass Lake
2. Cutfoot Exp. Forest
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PC2FM with PRISM climate data

Historic Mean Fire Intervals

< 1850 for any fire in 1 km^2

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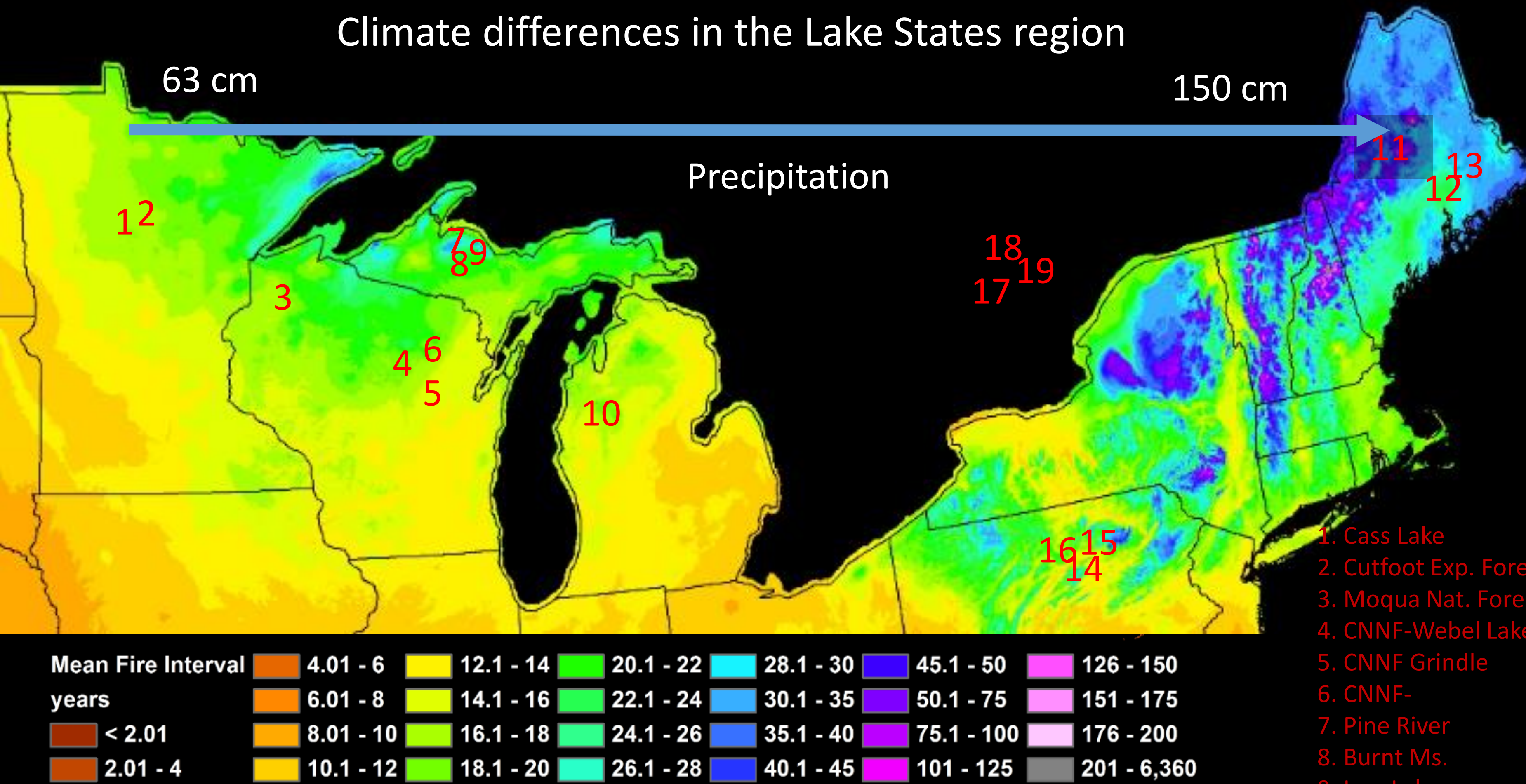
Climate differences in the Lake States region



1. Cass Lake
2. Cutfoot Exp. Forest
3. Moqua Nat. Forest
4. CNNF-Webel Lake
5. CNNF Grindle
6. CNNF-
7. Pine River
8. Burnt Ms.
9. Ives Lake
10. Wolf Lake
11. Joe-Mary Lakes
12. Gassabias Lake
13. 4th Machias Lake
14. Upper Dugan
15. Slate Run
16. Pine Creek
17. Opeongo Lake
18, Basin Lake
19. Algonquin Park

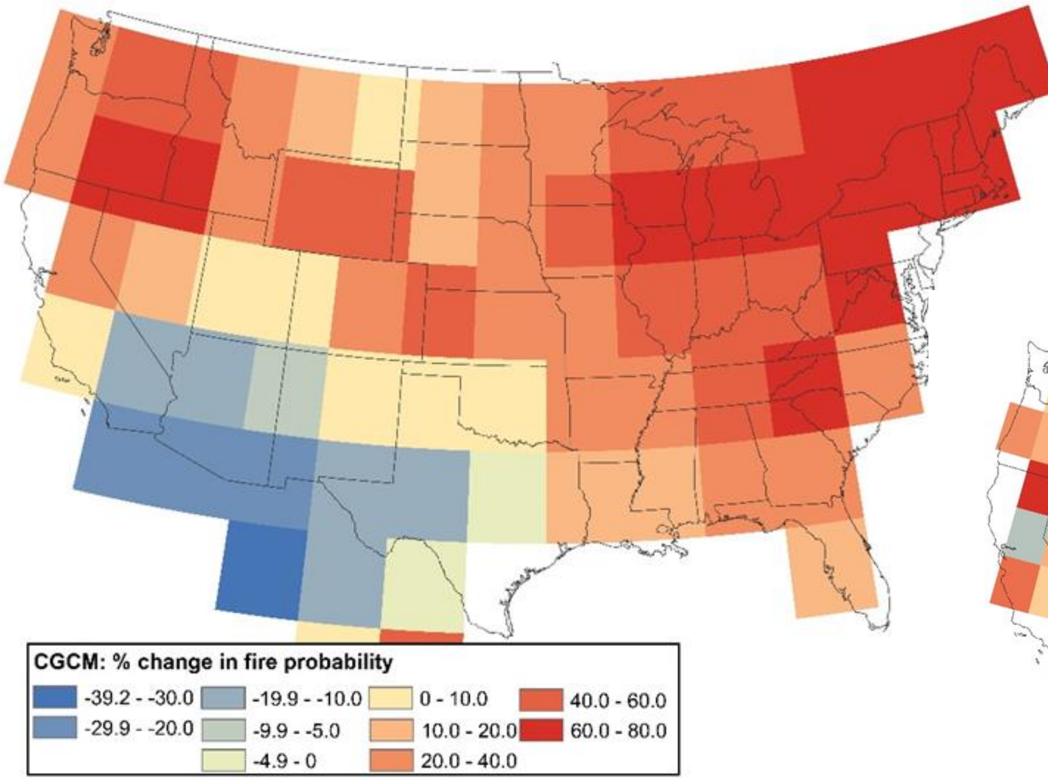
PC2FM with PRISM climate data

Historic Mean Fire Intervals

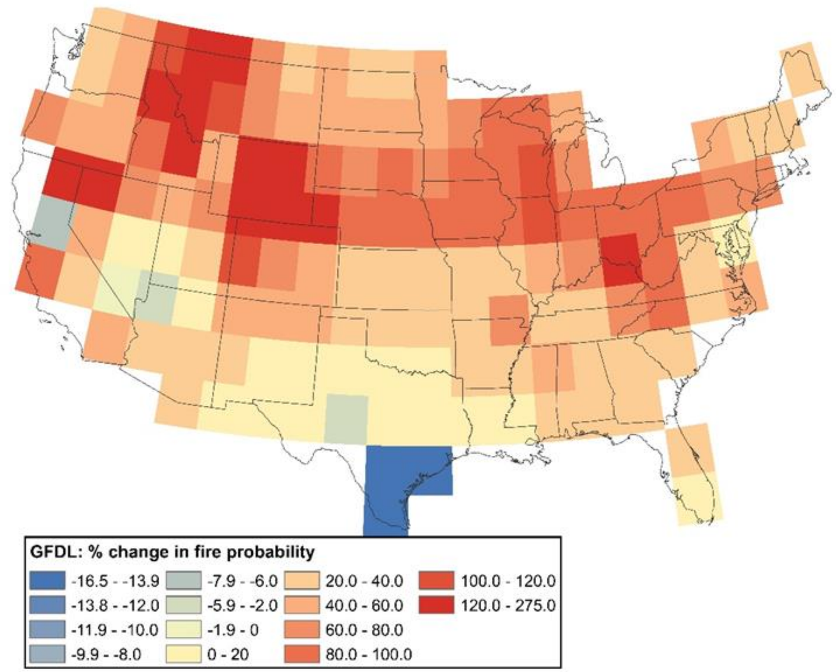
< 1850 for any fire in 1 km^2

Guyette, R.P., M.C. Stambaugh, D.C. Dey, and R.M. Muzika. (2012). Estimating fire frequency with the chemistry of climate. Ecosystems 15: 322-335. DOI: 10.1007/s10021-011-9512-0

Future (2090) changes (from 2010) in climate forced fire probability using data from two global climate models (GCM)



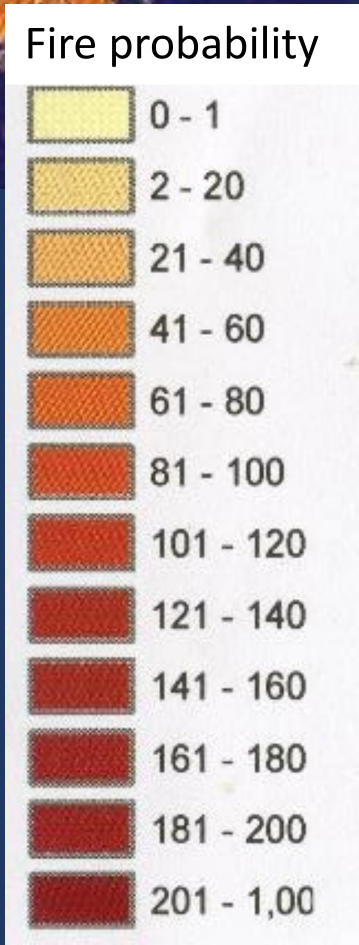
Coupled General Circulation Model 3.1 T47 (CGCM)



Geophysical Fluid Dynamics Laboratory (GFDL-CM2.1)

Guyette, R.P., F.R. Thompson, J. Whitter, M.C. Stambaugh, and D.C. Dey. 2014. Future Fire Probability Modeling with Climate Change Data and Physical Chemistry. Forest Science.13-108.

Future increases in fire probably near 2090 C E



Based on climate data from HADCM3
Baseline period 1900-1920

Higher elevations are the most effected in Michigan, New York, New Hampshire, Vermont and Maine.

This use of HADCM3 future data in modeling the Lake States Region results in all positive fire probability increases from about 40 to 100 percent.

Conclusions

Past

Frequent larger fires in the *western* Lake States

>topographic influence on fire spread

>more favorable weather conditions

Strong Native America influence both east and west

>location and local ignitions relevant

>mean fire intervals often driven by human ignitions every 10 to 50 years

>changing fire regimes often driven by canoe culture and commerce

Future

Climate modeling indicates 30 -100 % increase in climate forcing of fire

>moisture laden fuel regimes more at risk

>high elevations landscapes more influenced

>management: more people, more WUE, and more or less fire departments

>more people more ignitions

Further reading for fire information in Great Lakes red pine forests

Alexander ME Mason JA and Stocks BJ. 1979. Two and a half centuries of recorded forest fire history. Great Lakes Forest Research Centre, Environment Canada. Sault St. Marie, Ontario.

Drobyshev, I. Goebel, C., Hix, D., Corace R., and Semko-Duncan, M. 2008. Pre-and post-European settlement fire history of red pine dominated forest ecosystem of Seney National Wildlife Refuge, Upper Michigan. Can. J. For. Res. 38: 2497-2514.

Guyette RP and Dey DC. 1995. A pre-settlement fire history of an Oak-Pine Forest near Basin Lake, Algonquin Park, Ontario. Forest Research Report No. 132. Ontario Forest Research Institute, Saulte Ste. Marie, Canada.

Guyette RP and Dey DC. 1995. A dendrochronological fire history of Opeongo Lookout in Algonquin Park, Ontario. Forest Research Report No. 134. Ontario Forest Research Institute, Saulte Ste. Marie, Ontario, Canada.

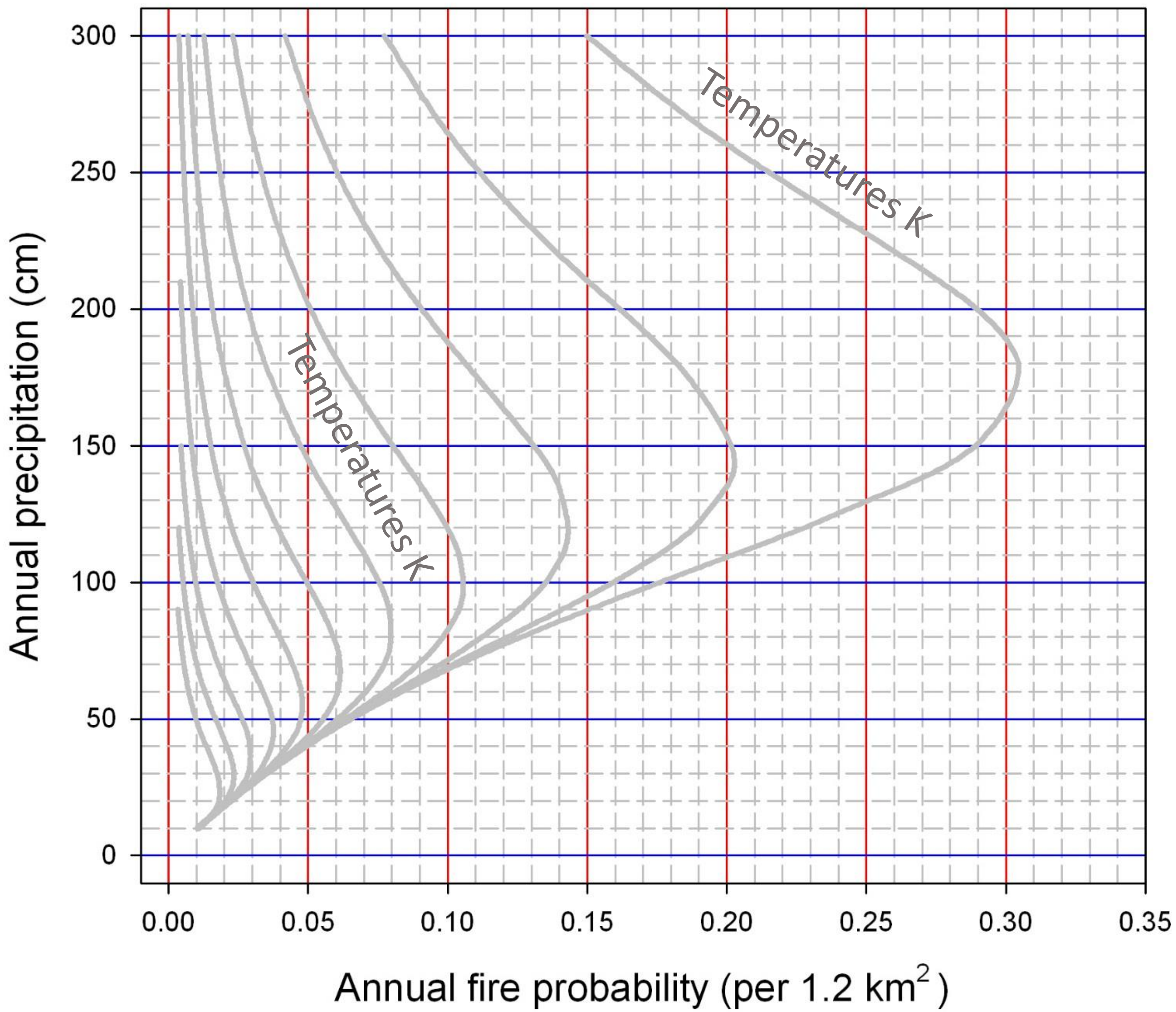
Loope WL and Anderton JB. 1998. Human vs. lightning ignition of presettlement surface fires in coastal pine forests of the upper Great Lakes. Am Midl Nat 140: 206-218.

Torretti RL 2003. Traditional stories from non-traditional stories: tree-rings reveal historical use of fire by Native Americans on Lake Superior's southern shore. Master’s Thesis, Northern Michigan University, Marquette, MI.

Combustion Dynamics Simulation Graph

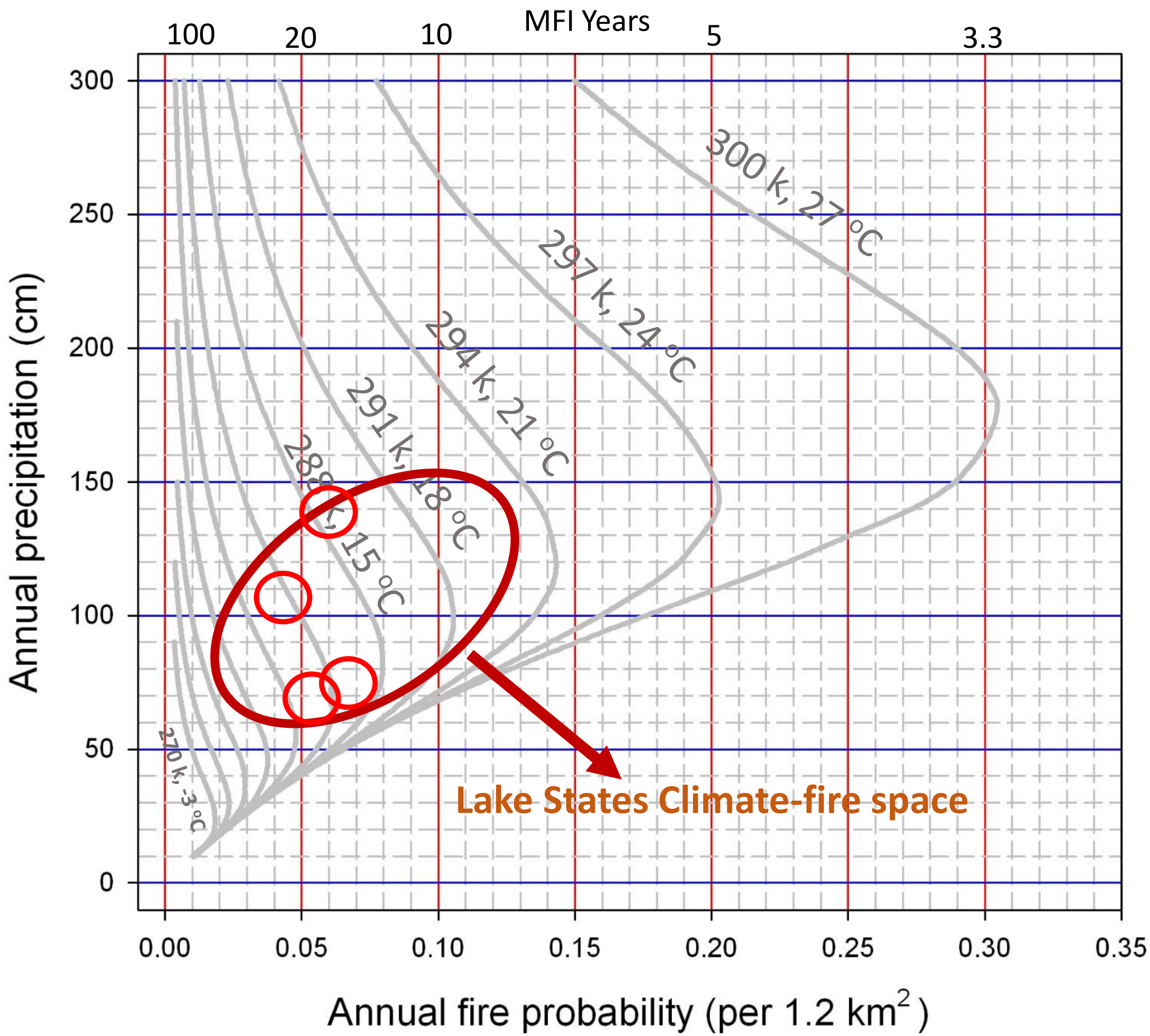
*Fire probability = 1/(**-4.3** + **1.7x10^{-28}**(A_o**e**$^{Ea/RT}$)+ 92(O_2(1/P^2/T))*

Fire probability graphed by model estimates



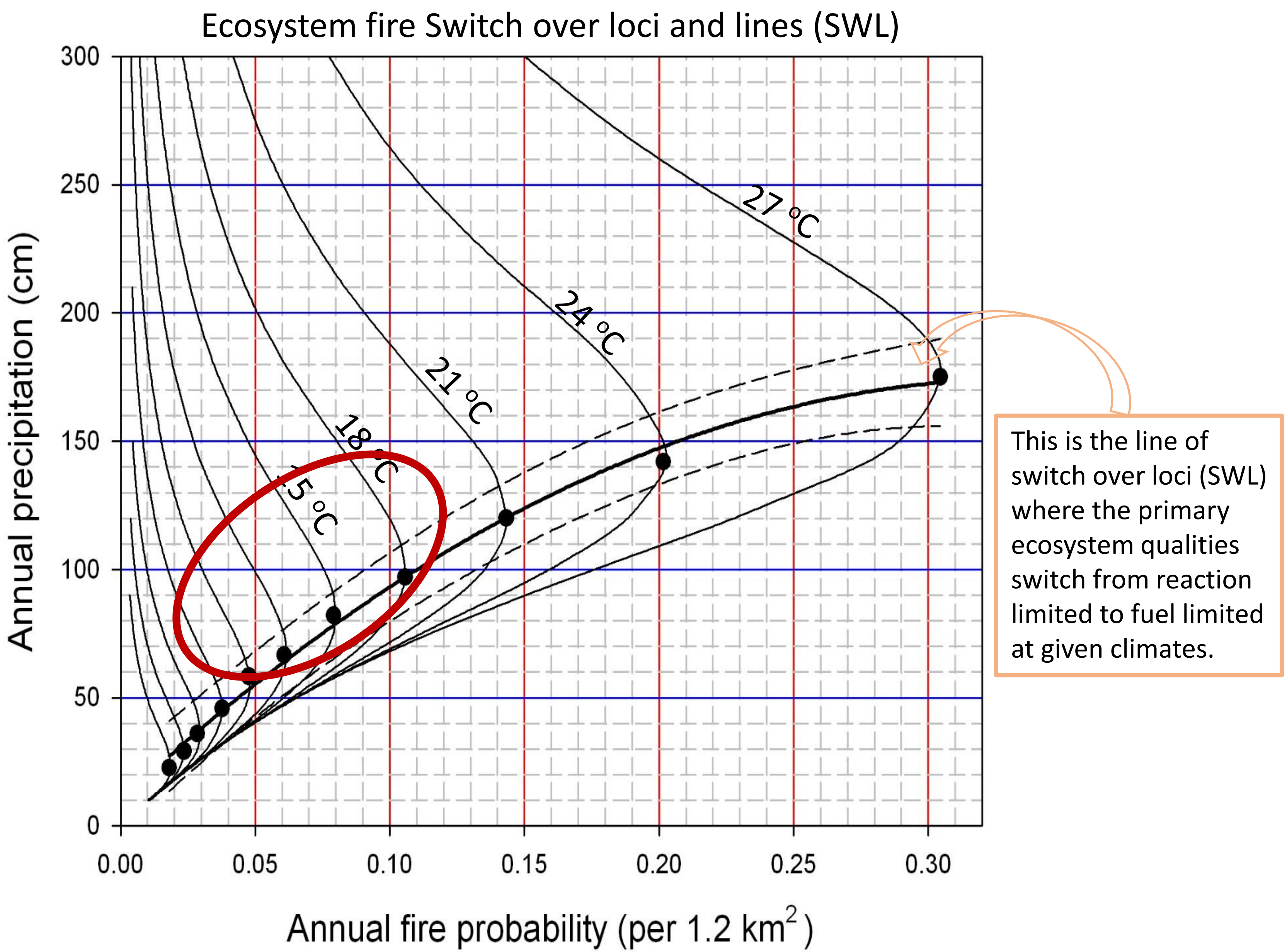
Combustion Dynamics Simulation Graph

Fire probability = 1/(-4.3 + 1.7x10^{-28}*(*$A_o e^{Ea/RT}$*)+ 92(*$O_2(1/P^2/T)$*))*



Combustion Dynamics Simulation Graph

Fire probability = $1/(-4.3 + 1.7x10^{-28}(A_o e^{Ea/RT}) + 92(O_2(1/P^2/T))$



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A Brief Introduction to the Facilitated Learning Analysis

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