PRESETTLEMENT FIRE FREQUENCY REGIMES OF THE UNITED STATES: A FIRST APPROXIMATION

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ABSTRACT

It is now apparent that fire once played a role in shaping all but the wettest, the most arid, or the most fire-sheltered plant communities of the United States. Understanding the role of fire in structuring vegetation is critical for land management choices that will, for example, prevent extinction of rare species and natural vegetation types. Pre-European fire frequency can be reconstructed in two ways. First is by dating fire scars on old trees, using a composite fire scar chronology. Where old fire-scarred trees are lacking, as in much of the eastern United States, a second approach is possible. This is a landscape method, using a synthesis of physiographic factors such as topography and land surface form, along with fire compartment size, historical vegetation records, fire frequency indicator species, lightning ignition data, and remnant natural vegetation. Such kinds of information, along with a survey of published fire history studies, were used to construct a map of presettlement fire frequency regions of the conterminous United States. The map represents frequency in the most fire-exposed parts of each landscape. Original fire-return intervals in different parts of the United States ranged from nearly every year to more than 700 years. Vegetation types were distributed accordingly along the fire frequency master gradient. A fire regime classification system is proposed that involves, rather than a focus on trees, a consideration of all vegetation layers.

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INTRODUCTION

The most important applications of fire history research are in land and timber management, restoration of natural communities, and restoration of habitat required by endangered species. Fire history is critical for understanding natural vegetation, and is a prerequisite for being able to map presettlement vegetation.

The Wisconsin glaciation ended about 10,000 years ago. A climate with relatively warm winters, similar to those we now experience, stabilized around 8,000 years ago. Most modern plant assemblages have remained relatively stable for the past 6,000 years (Webb 1988). Vegetation is dynamic and periods of drier or wetter climate, accompanied by higher or lower fire frequency have oscillated over the past 3,000 years (Swetnam 1993). Seasonality of fire has varied in some regions (Grissino-Mayer and Swetnam 1995), but these and minor Holocene climatic fluctuations such as the "little ice age," a slightly cooler period from AD 1450 to 1850, produced no substantial shifts in major plant formations (Webb 1988). The plant and animal communities found by the first European explorers, then, had been in place for several thousand years. It seems reasonable that these are the natural communities we would want to perpetuate. Fire history research can complement this goal.

The primary objective of this paper is to construct a map of fire frequency regions of the United States as they existed in one window of time, the era of European settlement. The intention is to visually relate fire history studies across the country to further appreciation of the pervasive role of fire in natural vegetation. The secondary objective is to classify fire regimes in terms of their effects on entire vegetation communities: the canopy, midstory, shrub and herb strata.

METHODS

Using Land Surface Form for Mapping Landscape Fire Regimes

Two steps were used in construction of the fire frequency map. First, information was compiled from fire history studies from across the country. Second, a map of land surface forms (Hammond 1964) was used as a starting point to put boundaries on presettlement fire frequency regions. Hammond's mapping units are shown in Table 1. Land surface form is essentially slope mapping, coded for the following: 1) percent of the landscape which is flat or gently sloping, 2) amount of local relief from the stream bottoms to ridge tops, and 3) whether the flat or gently sloping parts are located on uplands or in bottomlands. Hammond used these categories to classify landscape in the U.S. into 27 surface form categories (Table 2).

Hammond's land surface form map is uniquely useful in fire frequency mapping because the land surface units permit interpretation of the size of fire compartments and of the density of impediments to fire flow in the landscape. For example, his categories A1 (flat plains) and A2 (smooth plains) cover much of the southeastern coastal plain and the central prairie region

Table 1. Land surface form classification (Hammond 1964).

Units in Classification Scheme			
Slope (Capital letter)			
A	More than 80% of area gently sloping	C	20–50% of area gently sloping
B	50–80% of area gently sloping	D	Less than 20% of area gently sloping
Local relief (Numeral)			
1	0–30 meters	4	150–300 meters
2	30–90 meters	5	300–900 meters
3	90–150 meters	6	Over 900 meters
Profile type (Lower case letter)			
a	More than 75% of gentle slope is in lowland	c	50–75% of gentle slope is on upland
b	50–75% of gentle slope is in lowland	d	More than 75% of gentle slope is on upland

where there were once vast areas without a single firebreak. In contrast, some regions classified D4, such as the Ridge and Valley Province of the Appalachian Mountains, have dramatic relief of ravines and valleys with numerous streams to serve as firebreaks. Therefore, the expected fire frequency would be much lower in such regions.

On the other hand, land surface form does not provide much information about ignition rates, fire-return intervals, or variation in fire frequency due to latitude, climatic regions, and ignition factors. These, however, are accounted for in the actual fire-return intervals determined by fire history studies in the various parts of the country. The land surface form polygons circumscribe regions of relatively uniform types of relief, in which fire ignition rates, rates of spread, and other characteristics may be expected to remain within certain bounds. This permits approximate boundaries to be put on fire frequency regions.

Fire history studies, historical records, and my own experience with remnant natural vegetation, were used to assign fire frequency values to the map polygons. The studies used for mapping include many of those mentioned in Wright and Bailey (1982), Agee (1993), Brown et al. (1995b), Frost (1995), and Frost (1998). Where specific fire history studies were lacking, values were assigned using evidence of the kinds listed in Table 3. Where studies on adjacent polygons on the Hammond map showed the same type of fire regime, the polygons were merged.

The basic land surface form map of Hammond (1964) was further modified in several ways. Some boundary adjustments were made for the influence of soils and climate. Küchler's (1964) vegetation map units 40 (saltbush-greasewood), 43 (paloverde-cactus) and 46 (desert, vegetation largely absent), were added to distinguish barren desert and arid lands with fuel insufficient to carry fire. A map by Myers (Myers and Ewel 1990) was used to delimit infrequently burned sand pine scrub in Florida. Little's Atlas of North American Trees, Vol. 1 (1971) was consulted for ranges of fire frequency indicator tree species such as jack pine (*Pinus banksiana*), and a forest vegetation map based on satellite imagery (Zhu et al. 1993) was consulted for verification of major vegetation types.

Fire Compartment Size and Fire Frequency

A fire compartment is defined here as an element of the landscape with continuous fuel and no natural firebreaks, such that an ignition in one part would be likely to burn the whole. In developing the fire frequency map, I assumed that the larger the local fire compartments, the higher the fire frequency, since in large compartments there might be several lightning ignitions per year, yet any one ignition had the poten-

Table 2. Classes of land surface form (Hammond 1964).

Plains			
A1	Flat plains	A2	Smooth plains
B1	Irregular plains	B2	Irregular plains, high relief
Tablelands			
B3c, d	Tablelands, moderate relief	B5c, d	Tablelands, high relief
B4c, d	Tablelands, considerable relief	B6c, d	Tablelands, very high relief
Plains with hills or mountains			
A, B3a, b	Plains with hills	B5a, b	Plains with low mountains
B4a, b	Plains with high hills	B6a, b	Plains with high mountains
Open hills and plains			
C2	Open low hills	C5	Open low mountains
C3	Open hills	C6	Open high mountains
C4	Open high hills		
Hills and mountains			
D3	Hills	D5	Low mountains
D4	High hills	D6	High mountains

Table 3. Lines of evidence for approximating presettlement fire frequency and presettlement vegetation.

Asterisks suggest degree of usefulness, with three being most valuable. Usefulness of different kinds of evidence varies in different parts of the country.

Landscape and environmental evidence:	
***	Original fire compartment size.
**	Landscape factors which resist flow of fire between compartments (steep slopes, soils, water bodies).
**	Soil maps and observations of fire behavior on different soil types.
**	Charcoal deposition in varved lake sediments.
**	Lightning ignition records.
**	Records of size of areas burned by wildfires without suppression.
*	Charcoal deposition in soils or peat.
Historical evidence	
***	Historical records mentioning fire frequency indicator species and fire frequency indicator vegetation types.
***	U.S. General Land Office Survey witness tree records.
**	Historical references to fire or fire frequency.
**	Oral history (where land settled in past century).
**	Vegetation on old photos and aerial photos.
**	Tree species on old land survey plots.
Vegetation evidence:	
***	Fire scar analysis with tree ring chronologies.
***	Presence of remnant fire frequency indicator species.
**	Presence of remnant fire frequency indicator communities.
**	Observations of vegetation under known fire regimes.
**	Vegetation response to reintroduction of fire.
**	Vegetation response to fire exclusion.
**	Studies of succession on specific soil series under fire exclusion.
*	Degree of fuel continuity.

tial to burn the entire compartment. Many fire compartments, especially in Florida and the midwestern prairies, once contained more than 1,000 square kilometers without a natural firebreak. Before the fire landscape was partitioned by roads, ditches, and farms, some of these regions experienced nearly annual fire (Frost 1995, 1996, 1997). In more rugged topography, the fire compartments are much smaller, so that it would take many more ignitions to burn the same amount of land that might burn from a single ignition in flatter topography. As a result, expected fire frequency would be much lower, declining in proportion to decreasing compartment size.

Distinguishing Point Fire Frequencies, Area Frequencies, and Site Frequencies

Fire frequency is expressed as the average number of years between fires (mean fire-return interval). Agee (1993) pointed out that such figures are meaningless unless an indication is given of the size of the area being sampled. A point sample, such as the dates obtained from fire scars on a single tree, might yield a 10-year mean fire-return interval. This point frequency would likely be an underestimate, however, because very few trees are scarred by every fire (Kilgore and Taylor 1979, Swetnam et al. 1988, Caprio and Swetnam 1995). Since peculiarities of fuel distribution or wind affect whether or not a particular fire might scar a particular tree, standard fire history methodology uses scars from clusters of old trees and correlates the scar dates between trees into a composite fire scar chronology to give a more accurate picture of fire history.

Expanding the sampled area to the size of a state would add many more fires, giving fire-return intervals in weeks or months. Agee (1993) called these area samples or area frequencies. Area frequencies are useful on large sites, such as national forests, where they might predict that there will be, for example, an average of 3.2 fires per year on the forest. But for determining the fire frequency necessary to maintain a particular forest structure or to meet the needs of a fire-dependent rare plant species, a more ecologically significant measure of fire frequency is needed.

The fire frequency classes used in developing the fire map are neither point nor area frequencies, but are what I consider site frequencies. Ecologically, the local site or fire compartment is the most important level of scale. In terms of species biology, the mean fire-return interval for fire-dependent plants on a particular south slope is more important than the regional area frequency, since this is the true recurrence of fire experienced by those plants. Instead of using point or area frequencies I define a site as a fire compartment, therefore, a site frequency is the mean fire-return interval for a particular fire compartment.

Details in some published studies are adequate to determine whether or not the results are site frequencies. Guyette and Cutter (1991) compiled a fire scar chronology of an area of post oak savanna in Missouri about 2.5 square kilometers in size. Their maps of widely spaced trees scarred by the same fires over this whole landscape indicate that this was part of a single fire compartment, perhaps much larger than the study area. Later studies by Guyette and Dey (1995) on a 1 square kilometer site, by Dey and Guyette (1996) on a ½ square kilometer area of a white pine (*Pinus strobus*)-red pine (*Pinus resinosa*)-red oak (*Quercus rubra*) stand in Ontario, and by Caprio and Swetnam (1995) in individual giant sequoia (*Sequoiadendron giganteum*) groves, also appear to be site frequencies.

Classifying Ecological Fire Regime Types

Heinselman (1973) used a combination of fire frequency and severity to define seven fire regimes, with emphasis on crown fires of the kinds experienced in the Boundary Waters Canoe Area of Minnesota. Agee (1981) applied this system to forests of the Pacific Northwest and related fire severity to percent basal area of trees removed. Barrett and Arno (1991) used a different system to classify fire regimes on the Selway-Bitterroot Wilderness in relation to vegetation type and topography. More recently, to facilitate communication among foresters, a simplified classification of fires was made into 3 categories; nonlethal, stand replacement, and a mixture of these two, a "mixed fire regime" (Brown 1995, Brown et al. 1995a). Previous fire regime classifications have been mostly concerned with effects on timber species (Barrett and Arno 1991, Brown 1995). I use a more detailed ecological classification of fire regimes according to factors that appear to be of importance in determining vegetation structure and in maintaining habitat for understory species, including fire-dependent rare plants. Each fire regime is identified by a four character code, including characters for periodicity, season of burn, frequency, and ecological fire effects (Table 4).

Table 4. Coding for four components of fire regimes.

Fire regimes are assigned 4-character codes according to the scheme below. For example, the fire regime for ponderosa pine stands on the east slopes of the Oregon Cascades might be designated Ns2c: this could describe a particular site (fire compartment) where fairly regular late summer fires have occurred approximately 5 years apart, and the fires are typically light surface fires, reducing grass, shrubs and litter, while leaving trees intact. Where information was lacking in the original report I have estimated the seasonality, seaon of burn, or fire effects components. Fuel models refer to those of the National Wildfire Coordinating Group (1981). Note that ecological fire effects do not correlate well with fuel models.

Code	Description
Codes for periodicity of the fire cycle:[1]	
N	Nonrandom (clustered around a mean fire-return interval)
I	Irregular (tending toward random fire intervals)
P	Polycyclic (more than one kind of cycle)
Codes for primary season of burn:	
p	Spring
s	Summer
f	Fall
w	Winter
Codes for fire frequency classes (site mean fire-return intervals):	
1	1–3 years
2	4–6
3	7–12
4	13–25
5	26–100
6	100–500+
7	Never burned
Codes for ecological fire effects on vegetation:	
a	Nonpyrophytic (No fuel model)
b	Oligopyric (No fuel model)
c	Light surface fire, trees present (Fuel models 1,2, 8, 9)
d	Grass reduction (Fuel models 1, 3)
e	Understory thinning (Fuel models 9, 10)
f	Understory reduction (Fuel models 7, 9, 10)
g	Shrub reduction (Fuel models 4, 5, 6)
h	Canopy thinning (Fuel models 4, 6, 7)
I	Stand replacing (Fuel models 6, 10)
j	Ground fire (Beneath fuel models 1, 4, 6, 10)

[1] Sites with mean fire-return interval more frequent than 10 years were arbitrarily assigned to the clustered category.

Periodicity

In this category, fire-return intervals are classified into nonrandom (regular or predictable), irregular, and polycyclic. A limited number of published studies (Bragg 1991, Touchan et al. 1995), report standard error for the variation around the mean fire-return interval, which would be useful for distinguishing between regular and irregular fire-return intervals. In the absence of such statistics from the majority of studies, I have classified these categories subjectively and tentatively. Initially, fire-return intervals may appear to be irregular but sometimes are more or less tightly clustered around a mean. This might be expected since it may take a certain number of years for fuel patches in xeric ecosystems to coalesce to provide continuity for fire, or for a particular community to accumulate enough cured fuel to carry fire. I analyzed a cross-section of pyrophytic baldcypress (*Taxodium distichum*) from a peatland in Pamlico County, North Carolina, that dated from the year 1262 and had 729 rings. Fire scars and ring width measurements indicated a fairly regular fire-return interval in the pre-European era. The range was 4 to 25 years but most fires were clustered around the 12.8-year mean fire-return interval. In this case, a degree of regularity may have been imposed by the time required for fuel development in the fire source, a large, flammable pocosin which graded into the cypress stand. More work is needed on the relationship between fuel development and fire-return interval.

The term polycyclic describes communities with two or more kinds of fire cycles. In the southern Appalachians, fire history work with pitch pine (*Pinus rigida*)-Table Mountain pine (*P. pungens*) stands (Frantz and Sutter 1987, Sutherland et al. 1995), along with my own unpublished work in Linville Gorge, show that the typical fire regime on dry south slopes consists of a short cycle of fairly regular understory shrub-reduction fires, about 5–7 years apart, interrupted periodically by the long cycle of catastrophic stand-replacing fires about 75 years apart. Heinselman (1981) reported stands of red pine in the Lake States that were subject to three kinds of fire cycle on the same site: light, nonlethal understory fires; hotter, canopy-thinning understory fires, and stand-replacing fires. These cycles within cycles also account for much of the variability in some mixed-species northern and western conifer stands (Barrett and Arno 1991, Brown 1995).

Season of Burn

Communities were also coded for primary season of burn. In the Southeast, fire season begins in February-March in Florida (Myers and Ewel 1990), while to the north, in the southern Appalachians, the frequency of lightning ignitions, as well as the amount of land burned, both peak in May (Barden and Woods 1973). Bragg (1982) found the highest probability of fire in Nebraska prairies to peak in midsummer, with potential fires any time during the lightning season from March through November. Spring has been reported as the principal fire season in the Southwest (Pyne 1982), although large lightning fires are often ignited by summer thunderstorms.

In summer, convection storms create a background of lightning ignitions across most of the country and this may be the peak fire season in many areas. Swetnam et al. (1988) found the dominant presettlement fire season to be early- or mid-growing season at a site in southeastern Arizona, and Grissino-Mayer and Swetnam (1995) found that fires occurred throughout the growing season in southwestern New Mexico. In parts of the West, fire season culminates in August and September when senescent vegetation cures and becomes increasingly flammable. High temperatures and extreme low humidities then create severe burning conditions (National Wildfire Coordinating Group 1981).

Fire Frequency

Polygons were classified by the frequency with which fire occurred. Fire-return intervals were divided into seven classes: 1–3 years, 4–6 years, 7–12 years, 13–25 years, 26–100 years, 100 to over 500 years, and never burned. The more frequent classes are more finely divided because there are many herb layer species, especially some rare plants, which appear to be limited to specific frequent-fire regimes (Frost 1995, Frost 1998).

Ecological Fire Effects

The fourth letter in the fire regimes code represents ecological effects of fire. Previous classifications of fire regimes have focused largely on fire effects on trees. Most species diversity, however, occurs in the herb layer. The herb stratum provides habitat for the overwhelming majority of rare plants, and much of the species diversity used as food by wildlife. The following classification emphasizes fire effects on total vegetation structure. The ten fire effects categories are arranged roughly in order of increasing magnitude of ecological consequences.

a. Nonpyrophytic communities include those that are completely fireproof, such as tupelo swamps (*Nyssa aquatica*) with standing water, sparse vegetation clumps above treeline, talus slopes, rock outcrops, lava flows in the pioneer stages of succession, and completely barren deserts, playas and salt flats. It also includes some arid land vegetation lacking sufficient fuel continuity to carry fire.
b. Oligopyric sites ordinarily do not burn because of wetness or lack of fuel continuity, but may carry a surface fire under extraordinary conditions of wind or drought. This includes arid land vegetation a little denser than in nonpyrophytic sites, or wet sites like some black gum (*Nyssa biflora*) swamps, where prolonged drought can dry out leaf litter enough to carry surface fire.
c. Light surface fire refers to fires in hardwood leaf litter, thin grass, some forb-dominated communities, and light conifer litter. Typical examples include eastern oak-hickory forests with closed or partly open canopies, arid grasslands, frequently burned longleaf pine (*Pinus palustris*) and ponderosa pine (*Pinus ponderosa*) forests, and some Douglas-fir (*Pseudotsuga menziesii*) and larch (*Larix occidentalis*) stands. Effects include removal of litter, and reduction of grass and small woody stems (reduction means removal of aboveground biomass or killing stems to ground, whether or not they resprout). If frequent, they lead to bilayered stands with only tree canopy and herb layer.
d. Grass reduction refers to fires in grass-forb dominated communities like marshes, shortgrass and tallgrass prairie, eastern piedmont prairie, and western intermontane valley prairie, longleaf pine savannas (sparse trees), mountain grassy balds, and meadows. Most are dominated by perennial grasses and forbs that are reduced to the ground but quickly resprout from belowground rhizomes and other storage structures. Intensity can vary highly but is of little ecological importance since the result is the same—the stand is burned to the ground. Most live and dead fuel is consumed down to the mineral or wet muck substrate, even in marshes.
e. Understory thinning fires may be very light, only removing shrub and sapling stems up to 2 or 3 centimeters diameter, or they may burn hot enough to remove selected large subcanopy stems. If frequent, they dramatically restructure the community into bilayered stands with a tree canopy over a rich herb layer.
f. Understory reduction occurs in stands with flammable shrubs or heavy woody fuel accumulations in the understory. Fires are sufficiently intense to clean out everything but the canopy trees, most of which survive but may be heavily scorched. Some understory species may be killed outright while others resprout. Examples are pitch pine/ericad shrub communities of the New Jersey Pine Barrens, Table Mountain pine/ericad communities in the southern Appalachians, longleaf pine/*Serenoa repens* flatwoods in the southern Atlantic coastal plain and *Sequoiadendron giganteum-Pinus lambertiana*/shrub communities in California.
g. Shrub reduction describes shrub-dominated communities in which fires are typically intense and all stems are reduced to the ground. These include chamise, chaparral, some sagebrush types, canebrakes, low pocosin, and high pocosin. Most eastern species are prolific resprouters, while western shrublands include some species which do not resprout.
h. Canopy thinning occurs when fuel loadings, fuel moisture, and wind create prolonged or severe fire behavior but fall short of initiating crown fire. This is seen in communities dominated by Douglas-fir and many other western conifers (Wright and Bai-

ley 1982, Barrett and Arno 1991), and red pine in the Lake States (Heinselman 1981). I have also observed this effect in pitch pine/Table Mountain pine stands in the southern Appalachians.

i. Stand-replacing fire includes both crown fires and lethal understory fires (Barrett and Arno 1991). In either case, canopy stems are killed to the ground. Most trees are killed outright, while a few species, like pond pine (*Pinus serotina*), quaking aspen (*Populus tremuloides*), and many other hardwoods, can resprout from the ground.
j. Ground fire. Whatever the surface vegetation and fuel, fires sometimes ignite organic substrate. Peaty material may burn down to expose mineral soil, or may initiate ponding, followed by a decades- or centuries-long succession of plant communities while new peat is formed.

Fire Spread

The mean extent of area burned by fires is another significant fire regime variable. The fire compartment is the most accessible unit of area for defining the typical area burned. Under severe burning conditions, however, with fires accompanied by low humidity, low fuel moisture, high temperature, and high winds, fire may easily cross topographic and vegetation features that would serve as firebreaks under ordinary conditions. Fires once burned multi-state areas across the landscape of Kansas and Texas (Haley 1929, Bragg 1995). Determining spread of presettlement fires requires constructing master fire chronologies by cross dating fire scars on trees across a broad landscape. Composite fire scar chronologies developed by Baisan and Swetnam (1995), Caprio and Swetnam (1995), and Touchan et al. (1995), in the Southwest, show a pattern of frequent fires of limited extent, perhaps compartment fires, punctuated at longer intervals by fires that spread over the larger landscape. Because of the paucity of studies with composite fire chronologies in most of the U.S, however, no attempt was made to assign fire spread values to the studies in Table 5.

RESULTS AND DISCUSSION

Table 5 is a sampling of fire history work reported in the literature. Fire regime classification has been added to Table 5 according to the scheme described above. Values in the table were reported by the original authors or were interpreted from data. Missing information was sometimes inferred from other work in the same region.

Fire Frequency Map

Figure 1 represents local site fire-return intervals for the most fire-exposed parts of the landscape, especially flats, dry uplands, and south slopes. This should not be taken, however, to mean that the whole landscape burned at those frequencies. Varying proportions of the land within each map polygon were sites naturally protected from fire. Fire-safe sites in lowlands, for example, include islands, peninsulas (Harper 1911), some swamps, and some fluvial bottomlands. On uplands, naturally fire-sheltered sites include north slopes, mountain coves, ravines and steep-sided stream valleys, and portions of the landscape where waterways block fires swept by prevailing winds.

The map represents the highest fire frequencies commonly found within each region. For a particular fire frequency to be assigned to a polygon on the map, at least 10% of the landscape had to be judged to have had presettlement fire frequency that high. In some areas, such as tallgrass prairie or the southeastern coastal plain, the frequencies shown probably applied to 50% to 90% of the landscape. In some of the lower fire frequency polygons there are small areas that had higher frequency but did not seem extensive enough to meet the 10% criterion. The reason for emphasis on the higher fire frequencies that might be found in each region was to draw attention to the widespread distribution of landscapes with high presettlement fire frequency, and to the pervasive effects this had on woody vegetation structure, the herb layer, and habitat for species that are now rare.

Wherever possible, published fire scar chronologies were used for mapping, since these represent real data points in the landscape. Paradoxically, in the most frequently burned areas, fire scar dating is not always instructive since the resulting low-intensity fires may not produce any scarring. The more frequently a community is burned, the less intense will be the fires. For example, in Gates County, North Carolina, I examined a stand of 300-year-old longleaf pine that had experienced perhaps 100 fires over their lifetime, but not a single tree was scarred. By extension, underestimates may also occur with the most frequently burned ponderosa pine, larch, and other species, especially in lands where Native Americans carried out annual burns (Timbrook 1982). It seems likely that the fire-return intervals shown on the map are conservative. Thus, some of the areas mapped as having fire at 7–12 year intervals, may in reality have burned as frequently as 4–6 years, and some of the areas mapped 4–6 years may have burned at the 1–3 year interval. In prairies, Bragg (1982) found that areas burned in March accumulated enough fuel for a second fire in October or November, raising at least the possibility of a greater than annual fire frequency.

At the other end of the fire frequency spectrum, stand-replacing fires occurred at intervals ranging from 25 years (Heinselman 1981, Frost 1995) to more than 700 years (Schmidt 1957). Heinselman divided stand-replacing fires into three interval classes in the Lake States, and examples may also be found in many other parts of the country:

1) Short return interval (25–100 years). In the East this includes jack pine, sand pine (*P. clausa*), black spruce (*Picea mariana*) and some pitch pine and Table Mountain pine. It also includes some Atlantic white cedar (*Chamaecyparis thyoides*) stands, especially those on the margins of the great peat bogs

Table 5. Site fire frequencies reported for presettlement vegetation types.

Reported fire frequency	Fire regime type	Vegetation type, author, state
1	Np1g	Low pocosin/bog (Emmons 1860, Ruffin 1861, NC)
1–2	Np1d	Wet savannas—Venus flytrap sites (Frost, *this volume,* NC)
1.8	Np1d	Ponderosa pine (Dieterich 1980, AZ)
2	Np1g	Sandhills canebrakes (Hoffman, personal communication, NC)
1–3	Np1d	Longleaf pine savanna (Chapman 1926, LA)
1–5	Np1d	Oligohaline marsh (Frost 1995, VA, NC)
1–5	Np1g	Peatland canebrakes (Hughes 1966, NC)
2.2–13	Ns1c	Giant sequoia (AD 1000–1300, Swetnam 1993, CA)
3.2	Ns1c	Cedar glade (Guyette and McGinnes 1982, MO)
3.4	Ns1c	Mixed oak forest (Sutherland 1997, OH, historic period)
4.3	Ns2d	Post oak savanna (Guyette and Cutter 1991, MO)
4.8	Ns2d	Sandhills prairie (Bragg 1991, NE)
3–7	Np2d	Ponderosa pine (Boucher and Moody, *this volume,* NM)
5	Ns2e	Table Mountain pine (Sutherland 1995, VA)
4–6	Np2d	Brackish marsh (Frost 1995, NC)
4–6	Ns2c	Pyrophytic oak-hickory woodland (Frost 1995, 1996, NC, SC)
5.4	Ns2c	Ponderosa pine (Baisan and Swetnam 1995, MEX)
5.5	Ns2c	Ponderosa pine (Kilgore and Taylor 1979, CA)
5.7	Ns2d	Ponderosa pine (Grissino-Mayer and Swetnam 1995, NM)
7/75	Pp3f/Ps5i	(Polycyclic) Appalachian pitch pine (Frost, *this volume,* NC)
7.5	Np3d	Ponderosa pine (Jenkins et al., *this volume,* UT)
4.8–11.9	Np3d	Ponderosa pine (Weaver 1951, AZ, NM)
6–11	Ns3c	Douglas-fir (Arno 1976, MT Bitterroot Valley)
6–11	Ns3c	Ponderosa pine (Arno 1976, MT Bitterroot Valley)
7–10	Np3d	Aspen/grass (Baker 1925, UT)
9	Is3c	Lodgepole pine (Wright and Bailey 1982, Rocky Mountains)
~9/~43	Ps3c/Ps5i	(Polycyclic) Ponderosa pine (Baisan and Swetnam 1995, NM)
9.2	Ns3c	Giant sequoia (Kilgore and Taylor 1979, CA)
10	Ns3d	Desert grassland (Leopold 1924, southern AZ)
10.8	Ip3c	Douglas-fir (Wright and Bailey 1982, AZ)
10.9	Is3c	Incense cedar-sugar pine (Kilgore and Taylor 1979, CA)
11.8	Is3c	Red pine (Guyette and Dey 1995, Ontario)
10–18	Is4f	Giant sequoia (Kilgore and Taylor 1979, CA)
5–30	Ip4d	Grass-sedge fens (Heinselman 1981, MN)
10–30	Is4h	Pinyon-juniper (Leopold 1924, southern Arizona)
15–30	Is4h	Douglas-fir (Arno 1976, northern Rockies)
25	Is4f	Coast redwood (Fritz 1931, CA)
20–30	If4d	White pine (Wright and Bailey 1982, Lake States)
20–30	Ns4g	California chaparral (chamise) (Sweeney 1956, CA)
20+	Ns5g	Arizona chaparral (Cable 1975, AZ)
36/160	Ps5f/Ps6i	Red pine-white pine (Heinselman 1981, MN)
1–25/26–99/100–300	Ps4f/Ps5h/Ps6i	(3 kinds of cycles) Red pine (Heinselman 1981, Lake States)
25–40	Is5i	Black spruce (Wright and Bailey 1982, Lake States)
29–37	Is5f	Red pine (Burgess and Methven 1977, Ontario)
17–41	Is5g	Sagebrush-grass (Houston 1973, Yellowstone, WY)
25–50	Is5f	Lodgepole pine (Arno 1980, Northern Rockies)
20–60	Is5i	Sand pine (Cox and Roberts, *this volume,* FL)
43/117	Is5h/Is6i	Lodgepole pine-subalpine fir (Barrett and Arno 1991, ID and MT)
50	Is5i	Jack pine (Van Wagner 1978, MN)
72/181	Is5h/Is6i	Whitebark pine-subalpine fir (Barrett and Arno 1991, ID and MT)
50–300	Is6i	Peatland baldcypress (Frost 1995, NC)
25–300	Is6i	Peatland Atlantic white cedar (Frost 1987, 1995, VA, NC)
150–500	Is6i	Douglas-fir (Franklin et al. 1981, West Coast)
200	Is6i	Western Hemlock (Wright and Bailey 1982, West Coast)
700–800	Is6i	Sitka spruce (Wright and Bailey 1982, northwest coast)
700–800	Is6i	Pacific silver fir (Schmidt 1957, Pacific Northwest coast)

of northeastern North Carolina (Frost 1995). In the West, it includes aspen and a variety of mixed conifer stands (Agee 1981).

2) Long return interval (100–300 years). In the eastern U.S. this interval occurred in white cedar of the interior of the Great Dismal Swamp of Virginia and North Carolina (Frost 1995), and in a few small areas of white pine in various mixtures with eastern hemlock (*Tsuga canadensis*), white spruce (*Picea glauca*), red spruce (*Picea rubra*), red pine, balsam fir (*Abies balsamea*), sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), yellow birch (*Betula lutea*) and red maple (*Acer rubrum*), along the northern U.S. border from Michigan to Maine (Heinselman 1981).
3) Very long interval (more than 300 years). No intervals much longer than 300 years have been reported from the eastern U.S. In the West, however, a number of late seral conifers like Pacific silver fir (*Abies amabilis*), may be associated with cata-

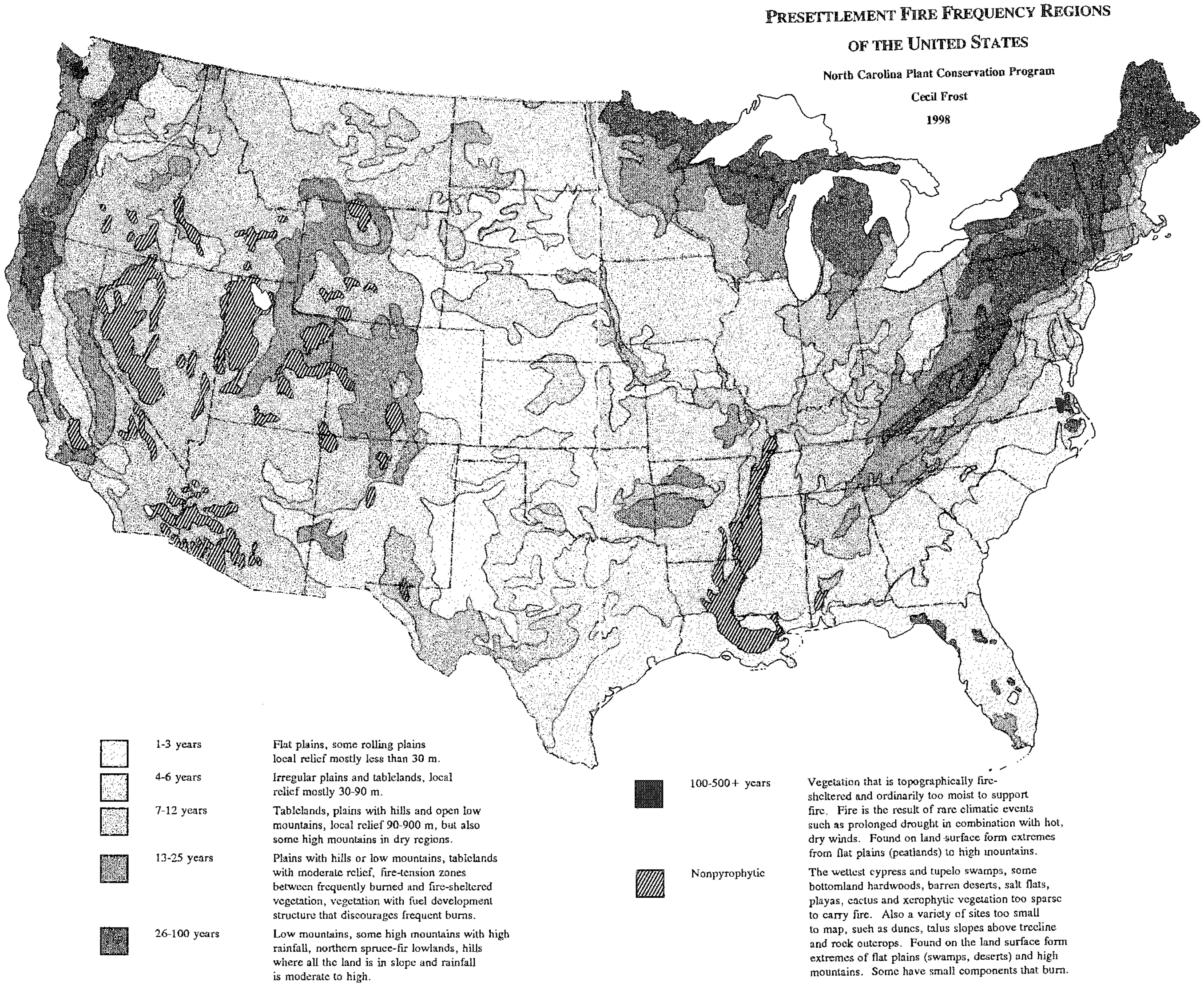

Fig. 1. First approximation map of presettlement fire frequency regions of the U.S. The frequencies illustrated represent the higher fire-return intervals to be found in each landscape unit.

strophic fire intervals up to 700–800 years (Wright and Bailey 1982).

Contrasts Between Eastern and Western Fire Ecology

In comparing fire ecology of vegetation of the eastern and western U.S., differences arise in terms of stand-replacing fires and in the periodicity of shrub fires. Stand replacement is the primary mode of regeneration for a number of conifers. In the East, the majority of natural stands of jack pine, black spruce, sand pine, pitch pine, Table Mountain pine and Atlantic white cedar were initiated by crown fires in previous stands of the same species. In western conifers, where fire regimes are more polycyclic, a variety of kinds of nonlethal understory fires may occur before a stand is killed by a catastrophic fire. Stand-replacing fires, however, are often reported in upland stands of lodgepole pine (*Pinus contorta*), some Douglas-fir stands, Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), western redcedar (*Thuja plicata*) and grand fir (*Abies grandis*)(Barrett and Arno 1991).

In another contrast between East and West, the eastern species listed above usually replace themselves immediately from seed, so that all fire does is replace an even-aged old stand with an even-aged new stand of the same species (jack pine, black spruce, sand pine, white cedar). In contrast, crown fire in western conifers often initiates a long succession beginning with early seral species, which are replaced by late seral species as the stand ages and the early species die out. In the minority, quaking aspen resprouts from the roots after fire (Fowells 1965), and a parallel occurs in the East with pond pine which resprouts from the base after intense pocosin fires.

Behavior and frequency of fire in shrub communities also differ between East and West. Chamise (*Adenostoma fasciculatum*) in California chaparral has been reported to require about 20 years between fires in order to accumulate enough size and dead wood to carry fire (Sweeney 1956). In contrast, southeastern canebrakes and some pocosins can burn every year or two (Emmons 1860, Hoffman 1994, Frost 1995). Chamise and chaparral burn with varying intensity depending upon shrub density, fuel moisture, humidity, temperature, and wind. In canebrake and pocosin, flame lengths of 12 meters are common.

Pre-European Ignition Sources: Lightning Versus Native Americans

Figure 1 shows fire frequency regions of the U.S. under the natural presettlement lightning fire regime, augmented in many places by Native American burning. The work by Komarek (1964, 1968, 1974) provided background on the role of lightning, and Pyne (1982) summarized the evidence for the Native American component. While there are many records of Native American burning, there is no consensus yet on the relative effects of Native American fires versus lightning ignitions. It seems likely that the effects of Native American burning varied drastically, and that whether or not Native Americans significantly influenced the local fire regime depended upon the background lightning fire regime associated with the landscape they lived in. This ranged from landscapes in which lightning ignitions are so frequent that effects of any Native American burning may have been negligible, such as the southeastern coastal plain, to lightning-infrequent regions where dense forest may have prevailed but for regular Native American burning, such as the Willamette Valley of Oregon (Agee 1993), or coastal California (Timbrook 1982).

Native Americans appear to have shifted seasonality of the fire in many areas (Bragg 1995). In northern mixed-grass prairie of the Dakotas, over 70% of lightning fires occur during July and August (Higgins 1984), but fires ignited by Native Americans from 1630 to 1920 exhibited two peaks, one in April and the second in October (Higgins 1986). In the southern mixed-grass prairie, however, the burning peak by Native Americans in mid- to late summer coincided with the lightning ignition peak (Moore 1972). In pre-European times, any post-lightning season fires in fall and winter would have been the result of burning by Native Americans. Byrd (1728) described the smoke from late fall Native American fires while surveying the Piedmont portion of the boundary line between Virginia and North Carolina.

The Atlantic and Gulf coastal plains were regions of almost annual fires over a large part of the landscape (Frost 1995), and it seems likely that in most years lightning preempted the fuel that Native Americans might have used. This also is the region with the most clearly fire-dependent plant species. Despite some skepticism (Agee 1993), there do seem to be distinctly fire-dependent species, and in the southeastern U.S. some, like *Lilium iridollae, Lysimachia asperulaefolia, Parnassia caroliniana* and many other rare species, seem to require a 1–3 year fire-return interval (Frost 1995). My ongoing plot studies in the Green Swamp of North Carolina indicate that one of the most fire-dependent species, Venus's flytrap (*Dionaea muscipula*), dies out when fire-return intervals become longer than 3 years.

Since any dependency on fire must involve evolutionary time, it seems unlikely that any rare species in the U.S. were dependent upon Native American burning. Native Americans have occupied North America only since the last glaciation—a relatively short time in evolutionary terms. Some long-lived species such as the redwoods have only undergone a few generations in that time. It follows that any truly fire-dependent species are lightning-ignition dependent. The remarkable adaptations of extreme frequent-fire species like longleaf pine and Venus's flytrap are unlikely to have appeared in the 10,000 years since the end of the Wisconsin glaciation, and may well have taken hundreds of thousands of years to evolve during previous interglacial periods. The existence of a highly fire-adapted species is, in fact, evidence for the greater importance of lightning ignitions over Native American burning in the southeastern coastal plain (Komarek 1964).

The relative importance of Native American fires should be expected to increase in topographically complex areas where fire compartments are smaller, and in regions with infrequent lightning ignitions. There are documented instances of changes in fire regime associated with Native American movements in such areas. In Missouri post oak savanna, fire frequency decreased after 1820 when the Osage and other Native American tribes began leaving in advance of European settlement (Guyette and Cutter 1991). In the giant sequoia-mixed conifer forests of California, there was also a drop in fire-scarring after elimination of burning by the Yokut and Monache in the early 1870's (Kilgore and Taylor 1979). Conversely, an increase in fire with the appearance of Iroquois settlements between 1360 and 1650 has been inferred by charcoal deposition detected in annually laminated lake sediments (Clark et al. 1996).

Native Americans were probably the more important ignition factor in the northeastern United States and the Pacific coastal fringe. In some places, regular Native American burning created isolated grasslands where forest otherwise would have prevailed. Examples are as widely scattered across the country as the Willamette Valley of Oregon (Agee 1993), the Shenandoah Valley of Virginia (Pyne 1982), and piedmont prairies of the Carolinas (Logan 1859).

Native American burning across the United States was carried out against a background of lightning ignitions. The lightning pattern on the landscape is complex (MacGorman et al. 1984). Hot spots of lightning activity occur in places like isolated mountain ranges while ignitions may be rare in the surrounding lowlands (Agee 1993:29). In the southeastern U.S. there are only a few records of Native American burning on the coastal plain, yet this is one of the highest fire frequency regions in North America. The coastal landscape also happens to be one of the physiographic regions with the largest fire compartments, many over

1,000 square kilometers without a natural firebreak. In Florida, lightning fires were a daily occurrence. During two lightning seasons, 1962 and 1963, there were 1,146 and 1,048 lightning fires, respectively, reported in Florida (Komarek 1964).

On the other hand, there were hot spots of Native American burning in the vicinity of their settlements (Clark et al. 1996). It should be possible to use physiography, climate, historical records of vegetation, and Native American history to map relative importance of Native Americans to lightning in maintaining the presettlement fire frequencies found in different parts of the country. When we compare maps of historical Native American burning with maps of lightning ignition frequency, we will find that the interplay between lightning and Native American ignitions was complex.

If we could distinguish the proportion of fire frequency due to Native Americans from that caused by lightning, it might raise the question of whether to manage lands for vegetation at only the lightning background frequency or to manage for the pre-European frequency, which was a combination of Native Americans and lightning. I suggest that we accept presettlement vegetation as the model for management of lands with natural vegetation since it had been around for some 6,000 years, in substantially stable composition, despite oscillations in rainfall and local effects related to movement of Native American settlements. If we do so, then it makes sense to include effects of Native Americans in the model, since they had the entire 10,000 years of the Holocene using fire to shape the vegetation we inherited (Pyne 1982). In some areas, such as the prairie region, it is impossible to separate lightning and anthropogenic effects, since Native American immigration and use of fire actually preceded development of the holocene grasslands (Bragg 1995).

Ultimately, within the stated objectives of this paper, it is not at all necessary to separate the relative effects of Native Americans and lightning. A primary objective was to develop a first approximation map of presettlement fire frequency regimes. This represents a window ranging from around 1565 to around 1890. The map is derived from findings of fire history studies, fire frequency indicator species, and historical records. As such it represents the actual role of fire in the presettlement landscape, regardless of the ignition source.

CONCLUSION

From Figure 1 it becomes evident that more than half the country contained large areas in which fire occurred at intervals between 1 and 12 years, while fire played some role in most of the rest. Thus the pre-European United States should be considered a fire landscape. Frequent light fires would have maintained bilayered stands with canopy and often dense, species-rich herb layers. Light, understory fires may have been the norm for millions of hectares of eastern hardwood forest, and some Douglas-fir and other western types. In modern fire-suppressed forests, however, herbs may be nearly eliminated by the dense litter accumulation (Frost 1998). Many rare fire-dependent and shade-intolerant species are the first to go. The continent-wide loss or depauperization of the pyrophytic herb layer following 20th century fire suppression is one of the unrecognized ecological catastrophes of landscape history.

In restoring fire, it is obvious that in the East, with its smaller islands of natural vegetation, people will have to be the primary ignition source, with lightning a very minor partner. In the West, however, lightning will play a more significant role, but will require human participation if we are to restore a more natural fire regime in place of the fire-suppression/fuel accumulation/catastrophic wildfire cycle that has become pandemic. Important lines of research will include construction of detailed presettlement vegetation maps at the soil series level, and maps showing local presettlement fire regimes, so that appropriate land management decisions may be made.

Until recently, most fire history work using fire scars has been done in the West where virgin stands of species like ponderosa pine have conspicuously fire-scarred bases. It has been long assumed that trees in the East rotted out too quickly to permit such methods. Recent fire scar analyses (Sutherland et al. 1995, Sutherland 1997), which cover the early settlement period in Ohio and the southern Appalachians, challenge this assumption.

The western hemisphere is so recently settled that the record of presettlement vegetation and fire frequency is still available in historical records, in herbarium records of fire frequency indicator species, in vegetation remnants, and within the rings of trees still standing. It is still possible to map or construct a reasonable approximation of presettlement fire history and vegetation of the entire United States at the soil series level. There remains only to do the work.

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