21 Altered Disturbance Regimes: the Demise of Fire in the Eastern United States

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Abstract We generated a series of maps to help alert and educate people to the pervasiveness of fire regime changes across the eastern United States. Using geographic information systems (GIS), fire regimes were assigned to spatial vegetation databases to depict past and current conditions. Comparisons revealed substantial reductions in fire throughout the East. The most dramatic shifts took place in the former Midwestern grasslands and across a broad swath of southern and central States where pine and oak communities historically dominated. Land-use changes (e.g., agricultural and forest-type conversions) and recent fire suppression largely explain these shifts. Fire regime change was least in northern hardwood systems, in the mixed mesophytic region, and within the Mississippi Embayment. Negative ecological consequences of prolonged fire suppression are mounting while restoration opportunities are waning.

Keywords Fire regime condition class, fire suppression, fire history, Native Americans, oak

21.1 Introduction

Ecosystems are the product of physical settings (e.g., climate, geology, soils), biota (plants and animals), and disturbance regimes. Ecosystems are dynamic (Pahl-Wostl, 1995), shifting states as components interact and change over time and space. Intriguingly, ecological research has been slow to grasp dynamism, focusing instead on equilibrium and stability to explain physical and biotic interactions (especially climate-site-vegetation relations) at the expense of disturbance (Christensen, 1991; Reice, 2001). Indeed, early ecological theories clearly bear this out (e.g., succession towards climax in the absence of disturbance; Clements, 1916). Fortunately, through mounting scientific evidence, perspectives have

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changed to embrace disturbance as an equally important, actually vital driver of ecological patterns, processes, and diversity (Watt, 1947; Denslow, 1980; Pickett and White, 1985; Oliver and Larson, 1996; Frelich, 2002). Even in climax systems, where autogenic (internal) processes were once thought to reign supreme, the role of allogenic (external) disturbances has been proven instrumental (Henry and Swan, 1974; Oliver and Stephens, 1977).

Disturbances affect biota in a wide variety of ways, from catastrophic extinction events (e.g. asteroid impacts or mass volcanism; Benton and Twitchett, 2003; McElwain and Punyasena, 2007) to chronic, less-destructive disturbances that help guide species evolution, adaptation, and assemblage (Grime, 1977). The term "disturbance regime" refers to the latter, encompassing an array of common, recurrent disturbances within a physical setting over a period of relative constant climate. In this context, species possessing life-history and physiological traits that "match" a given disturbance regime will express dominance, whereas those physiologically "ill equipped" will not (Bazzaz, 1979; Denslow, 1980; Osmond et al., 1987). This explains, in part, why hydrophilic trees grow on floodplains (Jackson and Colmer, 2005), fire-adapted trees dominate fire-prone areas (Lorimer, 1985; Abrams, 1996; Hengst and Dawson, 1994), and shade-tolerant trees proliferate in closed-canopied forests with gap-phase dynamics (Barden, 1979; Runkle, 1981 and 1982).

Humans have long enhanced or facilitated certain types of disturbances through their activities, thus directly affecting disturbance regimes. The global use of fire is most noteworthy (Stewart, 1956; Komarek, 1967; Sauer, 1975). Unfortunately, early North American scientists were slow to grasp the magnitude of Native burning, thus grossly underestimating its impacts on the environment (Stewart, 2002). Ecologists frequently misinterpreted pre-European vegetation as climatic climaxes rather than fire-maintained systems, while anthropologists viewed past cultures as merely reacting to the environment rather than being active participants. As a result, the concept of the environmentally benign Indian was firmly entrenched in science.

The consequences of Indian ignitions are most stark in moist temperate regions not conducive to burning, which is the case over most of the Eastern United States. Here, a long history of Native burning has produced a broad and diverse array of fire-based ecosystems (Little, 1974; Pyne, 1982; Wright and Bailey, 1982; Stewart 2002). As such, many Eastern species are adapted to and dependent on fire, either directly or indirectly (e.g.; jack pine (Pinus banksiana) and Kirtland's warbler (Dendroica kirtlandii); longleaf pine (Pinus palustris) and red-cockaded woodpecker (Picoides borealis)). Some plants actually reinforce fire regimes through the production of volatile compounds and flammable foliage (Mutch, 1970). With over 70 documented uses of fire (Lewis, 1993), Native Americans were an important ignition source, vastly augmenting natural causes (e.g., lightning) in most cases (Fahey and Reiners, 1981; Van Lear and Waldrop, 1989). In this respect, Native Americans were a "keystone species," actively managing the environment with fire over millennia (Sauer, 1975; Cronon, 1983). Due to the prevalence of fire, early European explorers and settlers encountered vast landscapes of fire-adapted (pyrogenic) vegetation, spanning from northern systems of spruce-fir (Picea-Abies), aspen-birch (Populus-Betula), and pine (Pinus) through oak-dominated (Quercus) central hardwoods to southern “pineries” and canebrakes (Wright and Bailey, 1982). Tallgrass prairies scattered throughout owed their existence to Native Americans who, through annual/biennial burning, maintained them for big game forage and hunting (grass → game → meat → satiated and flourishing families!).

European exploration, settlement, and land use fundamentally changed disturbance regimes of the East. Soon after first contact, a wave of Native depopulation, social disintegration, and displacement ensued, greatly changing the disturbance dynamics that formerly operated for thousands of years (Cook, 1973; Cronon, 1983; Denevan, 1992). With westward Euro-American expansion, forestlands were universally cut (aka, the “Great Cutover”), often subsequently burned, and many converted to agriculture (MacCleery, 1996). On areas allowed to reforest, deciduous tree species with disturbance adaptations (light-seeded, fast-growing pioneers; sprouters) often increased in importance at the expense of conifers (Nowacki and Abrams, 1992; Schulte et al., 2003). Natural systems rebounded where ongoing European activities mimicked past disturbance regimes, such as frequent surface burning of oak-hickory (Quercus-Carya) woodlands. In contrast, where European activities largely deviated from past disturbance regimes, wholesale changes in forest conditions occurred. For instance, a sizeable proportion of conifer-northern hardwoods (rich mesophytic systems that infrequently burned) converted to aspen-birch or oak through repeated cutting and burning (Graham et al., 1963; Nowacki et al., 1990; Schulte et al., 2003).

Social attitudes towards fire changed in the early 1900’s when outbreaks of destructive wildfires led to aggressive suppression efforts (Pyne, 1982; Stewart, 2002). This campaign with seemingly good intentions had major unforeseen ecological consequences across America. Without fire, open lands (grasslands, savannas, and woodlands) quickly succeeded to closed-canopied forests, followed by the eventual replacement of light-demanding, fire-dependent plants by shade-tolerant, fire-sensitive vegetation. Ground flora diversity in particular was negatively affected by forest conversion as light resources to the understory became limited (Anderson et al., 2000). These compositional and structural changes continue largely unabated today through ongoing fire suppression.

The fire dependency of many native plant communities necessitates that certain landscapes are managed with fire. This is an evolutionary-based principal that can not be ignored (Grime, 1977; Bazzaz, 1979). Indeed, without fire, the ecological integrity of pyrogenic ecosystems is compromised with accumulating species loss and biodiversity reduction. By comparing past and current fire regimes, the authors attempt to document the magnitude and pervasiveness of fire regime change and discuss the ecological consequences of such change in the Eastern United States.

21.2 Methods

Geographic information systems (GIS) and available vegetation data layers were used to depict past and current fire regimes and temporal changes. For consistency, only data layers spanning the entire Eastern United States were considered. Vegetation classes were assigned fire regime groups (Fig. 21.1) according to nation-wide fire regime condition class (FRCC) protocols (http://www.frcc.gov). All maps were uniformly rasterized at 1-kilometer pixels for analytical purposes.

Schmidt's et al., (2002) potential natural vegetation (PNV) map served as the basis to reconstruct past fire regimes (digital cover acquired through Jim Menakis, USDA Forest Service). Fire regime groups were assigned using Cecil Frost's "Presettlement fire frequency regions of the United States" map (Frost, 1998), other relevant literature (e.g.; Heinselman, 1973; Wright and Bailey, 1982; Wade et al., 2000), and expert opinion (see Table 21.1 and Acknowledgements).

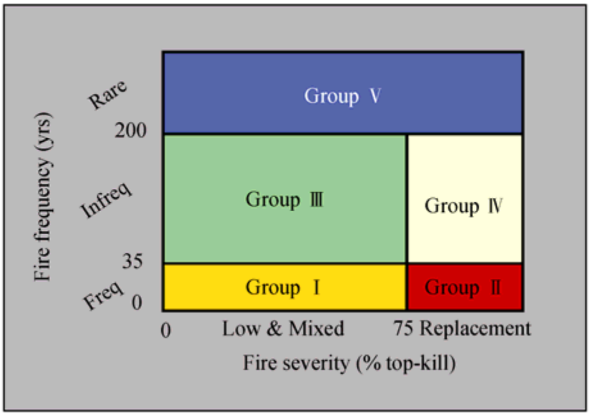

Figure 21.1 Five fire regime groups depicted along axes of fire severity and frequency. Criteria breakpoints are 75% top-kill for fire severity (low & mixed vs. replacement) and 35 yrs and 200 yrs for fire frequency (frequent, infrequent, and rare). Fire regime groups have been colored to reflect a fire gradient from extreme (red; Group Ⅱ) to rare (blue; Group Ⅴ)

Advanced very high resolution radiometer (AVHRR) and national land cover dataset (NLCD) layers were used in tandem to map current fire regimes. The individual classification power of the two datasets was capitalized on, maximizing the number of classes to depict current vegetation (theoretically increasing accuracy). As such, AVHRR data were used to classify forestlands (by type and cover class), whereas NLCD data were applied to the remaining lands, primarily non-forested openlands. Fire regime group assignments (Tables 21.2 and 21.3) were applied to produce a current fire regime map.

Table 21.1 Potential natural vegetation codes, titles, and assigned fire regime group

Code	Title	Fire Regime Group
32	Plains grassland	Ⅱ
33	Prairie	Ⅱ
36	Wet grassland	Ⅱ
38	Oak savanna (ND)	Ⅰ
39	Mosaic bluestem/oak–hickory	Ⅱ
40	Cross timbers	Ⅰ
41	Conifer bog (MN)	Ⅳ
42	Great Lakes pine forest	Ⅲ
43	Spruce–fir	Ⅳ
44	Maple–basswood	Ⅲ
45	Oak–hickory	Ⅰ
46	Elm–ash	Ⅴ
47	Maple–beech–birch	Ⅴ
48	Mixed mesophytic forest	Ⅲ
49	Appalachian oak	Ⅰ
50	Oak–northern hardwoods	Ⅲ
51	Northern hardwoods	Ⅴ
52	Northern hardwoods–fir	Ⅴ
53	Northern hardwoods–spruce	Ⅴ
54	Northeastern oak–pine	Ⅰ
55	Oak–hickory–pine	Ⅰ
56	Southern mixed forest	Ⅰ
57	Loblolly–shortleaf pine	Ⅰ
58	Blackbelt prairie	Ⅱ
59	Oak–gum–cypress	Ⅲ
60	Northern Floodplain	Ⅲ
61	Southern Floodplain	Ⅴ
62	Barren	Ⅱ

Table 21.2 Advanced very high resolution radiometer (AVHRR) vegetation class titles and assigned fire regime group by tree cover class

Title	0%—9%	10%—24%	25%—59%	≥60%
White-red-jack pine	Ⅱ	Ⅰ	Ⅲ	Ⅳ
Spruce-fir	Ⅱ	Ⅰ	Ⅲ	Ⅳ
Longleaf-slash pine	Ⅱ	Ⅰ	Ⅲ	Ⅳ
Loblolly-shortleaf	Ⅱ	Ⅰ	Ⅲ	Ⅳ
Oak-pine	Ⅱ	Ⅰ	Ⅲ	Ⅲ

(Continued)

Title	0%—9%	10%—24%	25%—59%	≥60%
Oak-hickory	Ⅱ	Ⅰ	Ⅲ	Ⅲ
Oak-gum-cypress	Ⅱ	Ⅰ	Ⅲ	Ⅲ
Elm-ash-cottonwood	Ⅱ	Ⅴ	Ⅴ	Ⅴ
Maple-beech-birch	Ⅱ	Ⅴ	Ⅴ	Ⅴ
Aspen-birch	Ⅱ	Ⅰ	Ⅲ	Ⅲ
Ponderosa pine	Ⅱ	Ⅰ	Ⅲ	Ⅳ
Lodgepole pine	Ⅱ	Ⅰ	Ⅳ	Ⅳ
Pinyon-juniper	Ⅱ	Ⅰ	Ⅳ	Ⅳ

Table 21.3 National land cover data (NLCD) vegetation codes, titles, and assigned fire regime group

Code	Title	Fire Regime Group
21	Low-intensity residential	Ⅴ
22	High-intensity residential	Ⅴ
23	Commercial/industrial/ transport	Ⅴ
31	Bare rock/sand/clay	Ⅴ
32	Quarries/strip mines/gravel pits	Ⅴ
33	Transitional	Ⅴ
41	Deciduous forest	Ⅴ
42	Evergreen forest	Ⅳ
43	Mixed forest	Ⅲ
51	Shrubland	Ⅰ
61	Orchards/vineyards/other	Ⅴ
71	Grasslands/herbaceous	II
81	Pasture/hay	Ⅳ
82	Row crops	Ⅴ
83	Small grains	Ⅳ
84	Fallow	Ⅴ
85	Urban/recreational grasses	Ⅳ
91	Woody wetlands	Ⅴ
92	Emergent herbaceous wetlands	Ⅳ

To spatially depict fire regime change over time, fire regime groups were reassigned Arabic numerals reflecting a fire gradient from hottest (most frequent and severe; ① to coolest (least frequent and severe; ② This Roman-to-Arabic conversion was not direct as the former did not best capture this fire gradient; which strikes diagonally from lower right (hottest) to upper left (coolest) in Fig. 21.1. Thus, the following values were applied: FRG Ⅰ =2, FRG Ⅱ =1, FRG Ⅲ =4, FRG Ⅳ =3 and FRG Ⅴ =5.

A fire regime change map was then generated on a pixel-by-pixel basis using the following equation:

$$\text{Fire regime change} = \text{Past fire regime group} - \text{Current fire regime group} \tag{21.1}$$

This formula projects past-to-current fire regime change over 9 classes from -4 through 0 to +4. Negative values represent reductions of fire (in terms of fire frequency and severity) on the landscape over time, whereas positive values indicate increased fire. The more negative or positive the values are, the more dramatic the trend.

21.3 Results and Discussion

Past and current fire regime maps are shown in Figs. 21.2 and 21.3, respectively. Color palettes reflect a fire regime gradient from highly “pyrogenic” systems that

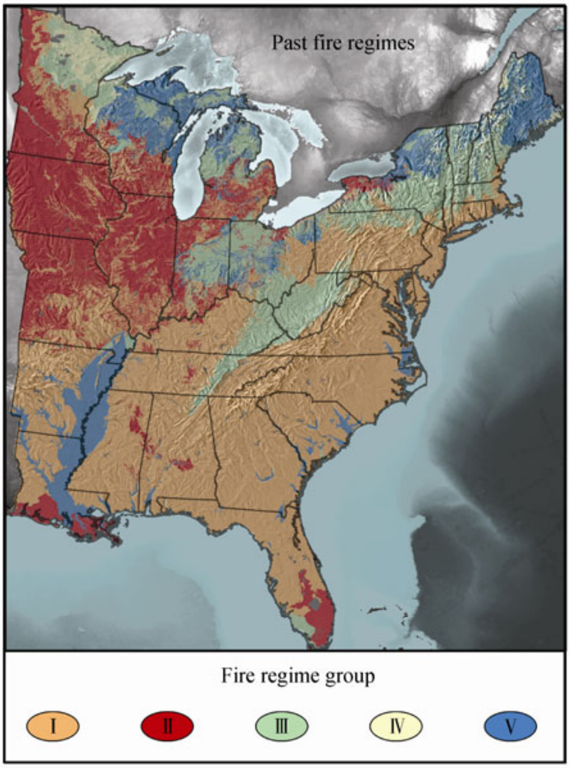

Figure 21.2 Past (presettlement) fire regimes by group based on potential natural vegetation (Schmidt et al., 2002). Fire regime group assignments of vegetation types are listed in Table 21.1

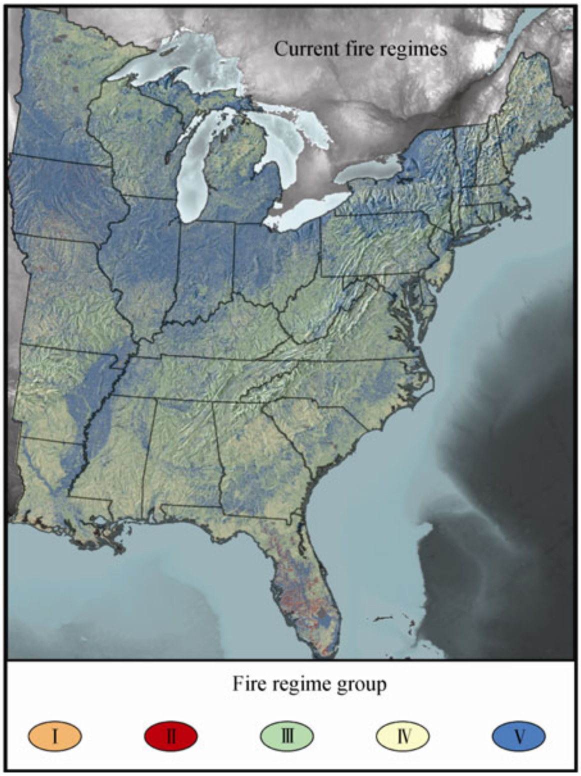

Figure 21.3 Current fire regimes by group based on the advanced very high resolution radiometer (AVHRR)-national land cover data (NLCD) hybrid map. Fire regime group assignments of vegetation types are listed in Table 21.2

burn most frequently and intensely (FRG Ⅱ; red) to "asbestos" systems that rarely burn (FRG Ⅴ; blue). Note that the color spectrum (red hot to cool blue) differs somewhat from fire regime group enumeration (FRG Ⅰ – Ⅴ).

Past fire regimes differed distinctly across the eastern United States as inferred from potential natural vegetation (Fig. 21.2). Historic fire regimes reflected a complex interaction among climate, vegetation, and topo-edaphic factors buoyed by human and natural ignitions (Jackson, 1968; Anderson, 1991). Fittingly, fire was most pronounced (FRG Ⅱ; red) within the Eastern, wedge-shaped extension of the Great Plains, known as the "Prairie Peninsula" (Transeau, 1935). Here, a large expanse of highly flammable grasses with few natural topographic barriers fostered hot, fast-spreading, near-complete burns (Jackson, 1965; Komarek, 1965; Anderson, 1991). Warm, dry conditions during dormant seasons (spring and fall) were especially favorable for fire outbreaks. Since tallgrass prairies are wholly dependent on burning for persistence, fires were undoubtedly frequent, probably occurring every year or so (Wells, 1970; Stewart, 2002). Rivers, lakes and dissected topography afforded some protection from fire such that surrounding lands, particularly on the lee side of prevailing winds, probably burned at lower severities allowing woodlands to develop (McComb and Loomis, 1944; Zicker, 1955; Grimm, 1984; Ebinger and McClain, 1991; Bowles et al., 1994). Correspondingly, a network of lower fire severity (FRG Ⅰ; orange) clearly appears along larger rivers across the former Prairie Peninsula (Fig. 21.2).

A fire regime of frequent, light surface burns (FRG Ⅰ; orange) historically extended south and east of the Prairie Peninsula, interrupted only by the Mississippi Alluvial Plain (FRG Ⅴ; blue) and the mixed mesophytic region of West Virginia and Eastern Kentucky (FRG Ⅲ; green). Here, on uplands, fire occurred in a variety of intensities and patchworks, creating mixes from grass and shrub openings to savannas, woodlands, and forests of oak and pine. Throughout the south, native forbs and wiregrass (Aristida) were well suited for light mosaic burning (Lemon, 1967; Walker and Peet, 1983), as were the southern pines (Greene, 1931; Chapman, 1932ab; Wright and Bailey, 1982; Landers, 1991; Wade et al., 2000). Stand-replacing, crown fires undoubtedly occurred under favorable fuel and weather (drought) conditions, adding to the landscape mosaic of age classes and vegetative types. Topographically protected areas, riparian zones, and swamps burned much less readily and harbored a greater collection of fire-sensitive plants. These areas occurred along larger coastal rivers and wetlands (FRG V; Fig. 21.2).

A fire regime of infrequent, mosaic-like surface burns (FRG Ⅲ; green) formed a historic interface between the “hotter” systems of the south and central states and cool, largely incombustible hardwoods to the north (Fig. 21.2). Here, a mix of fire-tolerant and fire-sensitive vegetation types occurred according to topography, landscape position, soils, and firebreaks (Grimm, 1984; Seischab, 1990; Cogbill et al., 2002; Whitney and DeCant, 2003). On drier uplands (coarse-textured soils, interfluves, ridgetops) periodic surface burns favored fire-dependent species of pine, oak, aspen, and birch. This burning regime allowed the famed northern pineries of jack, red (P. resinosa), and white pine (P. strobus) to develop on sandy outwash plains (Kilburn, 1960; Whitney, 1986; Cleland et al., 2004). On moister portions of the landscape (fine-textured soil, coves, riparian areas), fire impacts were much less, favoring mesophytic trees of beech (Fagus), maple (Acer), elm (Ulmus) and ash (Fraxinus) (Kaatz 1955).

Infrequent, stand-replacement fire regimes (FRG Ⅳ; yellow) were best represented by sub-boreal conifer forests (black and white spruce (Picea mariana and glauca), jack pine, balsam fir (Abies balsamea), tamarack (Larix laricina)) that extended southward from Canada into northern Minnesota and Maine. Fire was rare (FRG Ⅴ; blue) in certain northern landscapes where mesic ice-contact tills and wet-mesic glacio-lacustrine deposits supported beech-maple, elm-ash, northern hardwoods, and conifer-northern hardwoods. Fire was also limited in the Mississippi Alluvial Plain where flooding was the primary disturbance agent (Grimmett, 1989; Nelson, 1997; Foti, 2001; Tingle et al., 2001). Here, hydrophilic species dominate, such as bald cypress (Taxodium distichum), tupelo (Nyssa aquatica), and sweet gum (Liquidambar styraciflua).

Contemporary fire regimes are vastly more subdued across the Eastern United States (Fig. 21.3). Extensive stretches of FRG Ⅴ (blue) correspond with highly productive agricultural regions of the Midwest (Iowa and Southern Minnesota eastward through Ohio), the Mississippi Alluvial Plain, and along the Southeast Piedmont. The largely fire-resistant northern hardwood systems of Northern Wisconsin, Upper Peninsula of Michigan, Northern Pennsylvania, and New England also fall in this group. The remainder of the East was principally classified as FRGs Ⅲ (green) and Ⅳ (yellow) that burn infrequently, every 35 – 200 yrs.

There has been a dramatic "cooling" of the Eastern U.S. landscape when comparing past and current fire regimes (Fig. 21.4). This trend is consistent with the historical record, which points towards wholesale fire reduction, both spatially and temporally, across the East (Pyne, 1982; Abrams, 1992; Cutter and Guyette, 1994; Stewart 2002). The suppression of fire was due to convergence of events, including elimination of Native burning, building of road networks (providing fire breaks and access), forest/prairie conversion to croplands (fuel change/reduction), and aggressive 20th century fire fighting.

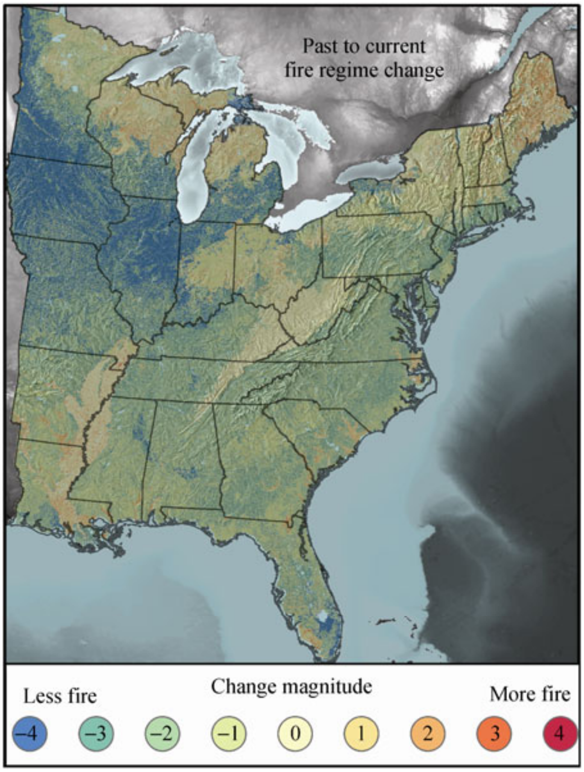

Figure 21.4 Past-to-current fire regime change map based on spatial analysis of PNV (past) and AVHRR-NCLD (current) fire regime maps. Positive values represent shifts towards more fire, whereas negative values represent shifts to less fire. The departure from zero relates to the extent of fire regime change

The largest reductions of fire (depicted in blue) were centered in the Midwest forming a crescent from southern Minnesota through northern Ohio. Here, the conversion of historic grasslands and open woodlands to an agriculture-dominated landscape largely explains this abrupt change (Wells, 1970; Iverson and Risser, 1987). The few areas not converted to agricultural production (cropland or pasturage) were quickly occupied by trees due to fire suppression (Loomis and McComb, 1944; Cottam, 1949). Agricultural conversion and fire exclusion, in concert, largely explain why tallgrass prairies and oak savannas are now considered the rarest ecosystems of North America (Nuzzo, 1986). Success of restoring open systems quickly diminishes upon conversion to closed-canopied forests (Anderson et al., 2000).

Substantial reductions of fire (represented by aqua-greens) stretched across the southern two-thirds of the Eastern United States, excluding the Mississippi Alluvial Plain and the mixed mesophytic region of West Virginia and eastern Kentucky, which remained largely unchanged (yellow). Here, in the absence of fire, pine- and oak-dominated systems are readily converting to fire-sensitive, shade-tolerant species (Chapman, 1932b; Fralish et al., 1991). Eastern oak forests are illustrative of the ecological ramifications of these changes (Appendix A).

Slight decreases in fire regime (light green) were found in northern Minnesota (consistent with Heinselman, 1973) and on the Tipton Till Plain of Indiana and Ohio extending eastward across most of southern and central New England. Here, depending on site conditions, sugar and red maple (Acer saccharum; A. rubrum) have been major benefactors of fire reduction (Abrams, 1992). These mesophytic species further “fire-proof” conditions by deep shading (promoting cooler and moister understory conditions) and producing non-flammable fuel beds (moist, rapidly decaying woody debris; wet, flaccid foliage accumulation in the fall).

Some exceptions to the above trends exist, though fire increases (oranges and reds) were less pronounced and generally scattered in small pockets (Fig. 21.4). The most conspicuous concentrations of increased burning were in Maine and Northern Wisconsin and Michigan. The projected increase in fire in the Upper Great Lakes states is probably an artifact of elevated levels of aspen-birch and off-site pine plantations (both fire-dependent forest types) on former Northern hardwood sites. The fire increase in Maine might be anomaly, given sequential decreases in area burned over the past century (Fahey and Reiners, 1981). However, some of the largest fires in Maine did occur in 1947 (Patterson, 1991), which would reflect in the current vegetation (and thus the current fire regime). Lastly, the generalness of PNV classes used to depict past fire regimes (northern hardwood-spruce forests; FRG V) compared to the preciseness of AVHRR-NLCD classes for current fire regimes (spruce-fir; FRG IV) might further explain this portrayed increase. As such, the coarse-scale maps generated by this analysis must be used with caution and limited to general application and interpretation.

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Appendix A The Eastern Oak Story

Oaks historically covered a large portion of the Eastern United States, forming common associations with pine, chestnut, and hickory. These fire-dependent systems were maintained by frequent, Native-ignited surface burns. Europeans profoundly altered the disturbance regime through land use and non-native species introduction. The first wave of logging concentrated on Eastern white pine—a preferred timber-producing tree. Thereafter, hardwoods (oaks, chestnut, and hickories) were harvested and oftentimes maintained through repetitive clear cutting, which encouraged sprout regeneration. This intense harvesting regime coupled with recurring wildfires largely favored hardwoods over conifers (i.e. pines). Three significant things happened in the early portion of the twentieth century: ① harvesting eased ② chestnut blight (effectively wiping out American chestnut), and ③ active fire suppression (the “Smokey Bear” campaign). These interrelated phenomena allowed oaks to dominate and form closed-canopied forests. Over the past century, native ground cover largely decreased due to low light levels, lack of surface fires, and unprecedented white-tailed deer foraging. In the meantime, fire-sensitive, shade tolerant mesophytic species (sugar and red maple, beech, black cherry, black gum) have flourished and now dominate understories. Under these conditions, overstory oak is quickly replaced by subordinate mesophytic trees upon death. Gypsy moth (an introduced insect) further accelerates this transition by preferentially attacking and weakening overstory oaks, causing their early demise and replacement. Without ecological restoration in the form of silvicultural treatments (thinning and prescribed burning), these systems will continue to decline (in terms of species richness and ecological function), converting from oak to mesophytic forests within a generation. Effects on native wildlife populations dependent of large-seeded trees producing acorns and nuts are equally imperil.

References

Abrams M, (1992), Fire and the development of oak forests. *BioScience*, **42**: 346 – 353

Abrams M, (1996), Distribution, historical development, and ecophysiological attributes of oak species in the eastern United States. *Ann. Sci. For.*, **53**: 487 – 512

Anderson RC, (1991), Presettlement forests of Illinois. pp.9 – 19 in Burger GV, Ebinger JE, Wilhelm GS (eds.), Proceedings of the Oak Woods Management Workshop, Eastern Illinois University, Charleston, IL, 65 – 73

Anderson RC, Schwegman JE, Anderson MR, (2000), Micro-scale restoration: A 25-year history of a southern Illinois Barrens. *Restoration Ecology*, **8**: 296 – 306

Barden LS, (1979), Tree replacement in small canopy gaps of a *Tsuga canadensis* forest in the southern Appalachians, Tennessee. *Oecologia*, **44**: 141 – 142

Bazzaz FA, (1979), The physiological ecology of plant succession. *Ann. Rev. Ecol. Syst.*, **10**: 351 – 371

Benton MJ, Twitchett RJ, (2003), How to kill (almost) all life: the end-Permian extinction event. *TRENDS in Ecology and Evolution* **18**(7): 358 – 365

Bowles ML, Hutchison MD, McBride JL, (1994), Landscape pattern and structure of oak savanna, woodland, and barrens in northeastern Illinois at the time of European settlement. P. 65 – 73 in J.S. Fralish, R.C. Anderson, J.E. Ebinger, and R. Szafoni (eds), Proceedings of the North American Conference on Barrens and Savannas, October 15 – 16, 1994, Illinois State University, Normal, IL

Chapman HH, (1932a), Is the longleaf type a climax? *Ecology*, **13**: 328 – 334

Chapman HH, (1932b), Some further relations of fire to longleaf pine. *Journal of Forestry*, **30**: 602 – 603

Christensen NL, (1991), Wilderness and high intensity fire: How much is enough? *Tall Timbers Fire Ecology Conference Proceedings*, **17**: 9 – 24

Cleland DT, Crow TR, Saunders SC, Dickman DI, Maclean AL, Jordan JK, Watson RL, Sloan AM, Brosofske KD, (2004), Characterizing historical and modern fire regimes in Michigan (USA): A landscape ecosystem approach. *Landscape Ecology*, **19**: 311 – 325

Clements FE, (1916), Plant succession: An analysis of the development of vegetation. Carnegie Institute Washington Publication No. 242

Cogbill CV, Burk J, Motzkin G, (2002), The forests of presettlement New England, USA: Spatial and compositional patterns based on town proprietor surveys. *Journal of Biogeography*, **29**: 1279 – 1304

Cook SF, (1973), The significance of disease in the extinction of the New England Indians. *Human Biology*, **45**: 485 – 508

Cottam G, (1949), The phytosociology of an oak wood in southwestern Wisconsin. *Ecology*, **30**: 271 – 287

Cronon W, (1983), Changes in the land: Indians, colonists and the ecology of New England. Hill and Wang, New York, NY

Cutter BE, Guyette RP, (1994), Fire frequency on an oak-hickory ridgetop in the Missouri Ozarks. *American Midland Naturalist*, **132**: 393 – 398

Denevan WM, (1992), The pristine myth: The landscape of the Americas in 1492. *Annals of the Association of American Gegraphers* **82**: 369 – 385

Denslow JS, (1980), Patterns of plant species diversity during succession under different disturbance regimes. *Oecologia*, **46**: 18 – 21

Ebinger JE, McClain WE, (1991), Forest succession in the Prairie Peninsula of Illinois. *Illinois Natural History Survey*, **34**:375 – 381

Fahey TJ, Reiners WA, (1981), Fire in the forests of Maine and New Hampshire. *Bulletin of the Torrey Botanical Club*, **108**: 362 − 373

Foti TL, (2001), Presettlement forests of the Black Swamp Area, Cache River, Woodruff County, Arkansas, from notes of the first land survey. P. 7 − 15 in P.B. Hamel, and T.L. Foti (eds), Bottomland hardwoods of the Mississippi Alluvial Valley: Characteristics and management of natural function, structure, and composition. USDA Forest Service General Technical Report SRS-42

Frelich LE, (2002), Forest dynamics and disturbance regimes: Studies from temperate evergreen-deciduous forests. Cambridge University Press, Cambridge, UK

Frelish JS, Crooks FB, Chambers JL, Harty FM, (1991), Comparison of presettlement second-growth and old-growth forest on six site types in the Illinois Shawnee Hills. *American Midland Naturalist*, **125**: 294 − 309

Frost CC, (1998), Presettlement fire frequency regimes of the United States: A first approximation. Tall Timbers Fire Ecology Conference Proceedings, **20**: 70 − 81

Graham SA, Harrison RP Jr., Westell CE Jr., (1963), Aspens: Phoenix trees of the Great Lakes region. University of Michigan Press, Ann Arbor, MI

Greene SW, (1931), The forest that fire made. *American Forests*, **37**: 583 − 584, 618

Grime JP, (1977), Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *American Naturalist*, **111**: 1169 − 1194

Grimm EC, (1984), Fire and other factors controlling the Big Woods vegetation of Minnesota in the Mid-Nineteenth Century. *Ecological Monographs*, **54**: 291 − 311

Grimmett, HK, (1989), Early plant and animal communities of the Arkansas Delta. *Arkansas Historical Quarterly*, **48**: 101 − 107

Heinselman ML, (1973), Fire in the virgin forests of the Boundary Waters Canoe Area, Minnesota. *Quaternary Research*, **3**: 329 − 382

Hengst GE, Dawson JO, (1994), Bark properties and fire resistance of selected tree species from the central hardwood region of North America. *Canadian Journal of Forest Research*, **24**: 688 − 696

Henry JD, Swan JMA, (1974), Reconstructing forest history from live and dead plant material—an approach to the study of forest succession in southwest New Hampshire. *Ecology*, **55**: 772 − 783

Iverson LR, Risser PG, (1987), Analyzing long-term changes in vegetation with geographic information system and remotely sensed data. *Advances in Space Research*, **7**: 183 − 194

Jackson AS, (1965), Wildfires in the Great Plains grasslands. Tall Timbers Fire Ecology Conference Proceedings **4**: 241 − 259

Jackson MB, Colmer TD, (2005), Response and adaptation by plants to flooding stress. *Annals of Botany*, **96**: 501 − 505

Jackson WD, (1968), Fire, air, water and earth—an elemental ecology of Tasmania. Proceedings of the Ecological Society of Australia **3**: 9 − 16

Kaatz MR, (1955), The Black Swamp: A study in historical geography. *Annuals of the Association of American Geographers* **45**:1 − 35

Kilburn PD, (1960), Effects of logging and fire on xerophytic forests in Northern Michigan. *Bulletin of the Torrey Botanical*, *Club*, **87**: 402 − 405

Komarek EV Sr., (1965), Fire ecology—grasslands and man. Tall Timbers Fire Ecology Conference Proceedings, **4**: 169 – 220

Komarek EV Sr., (1967), Fire—and the ecology of man. Tall Timbers Fire Ecology Conference Proceedings, **6**: 143 – 170

Landers JL, (1991), Disturbance influences on pine traits in the southeastern United States. Tall Timbers Fire Ecology Conference Proceedings, **17**: 61 – 98

Lemon PC, (1967), Effects of fire on herbs of the southeastern United States and central Africa. Tall Timbers Fire Ecology Conference Proceedings, **6**: 113 – 127

Lewis HT, (1993), Patterns of Indian burning in California: Ecology and ethnohistory, pp 55 – 116 in Blackburn TC, Anderson K (eds.), Before the wilderness: Environmental management by Native Californians, Ballena Press, Menlo Park, CA

Little S, (1974), Effects of fire on temperate forests: Northeastern United States, pp 225 – 250 in Kozlowski TT, Ahlgren CE (eds.), Fire and ecosystems. Academic Press, New York, NY

Loomis WE, McComb AL, (1944), Recent advances of the forest in Iowa. *Iowa Academy of Science*, **51**: 217 – 224

Lorimer CG, (1985), The role of fire in the perpetuation of oak forests, pp 8 – 25 in Johnson J (ed.), Challenges in oak management and utilization, University of Wisconsin Cooperative Extension Service, Madison, WI

MacCleery DW, (1996), American forests: A history of resiliency and recovery. Forest History Society Issues Series, Forest History Society, Durham, NC

McComb AL, Loomis WE, (1944), Subclimax prairie. *Bulletin of the Torrey Botanical Club*, **71**: 46 – 76

McElwain, JC, Punyasena JC, (2007), Mass extinction events and the plant fossil record. *Trends in Ecology and Evolution*, **22**: 548 – 557

Mutch RW, (1970), Wildland fires and ecosystems—A hypothesis. *Ecology*, **51**: 1046 – 1051

Nelson, JC, (1997), Presettlement vegetation patterns along the 5th Principal Meridian, Missouri Territory, 1815. *American Midland Naturalist*, **137**: 79 – 94

Nowacki GJ, Abrams MD, (1992), Community, edaphic, and historical analysis of mixed oak forests of the Ridge and Valley Province in central Pennsylvania. *Canadian Journal of Forest Research*, **22**: 790 – 800

Nowacki GJ, Abrams MD, Lorimer CG, (1990), Composition, structure, and historical development of northern red oak stand along an edaphic gradient in north-central Wisconsin. *Forest Science*, **36**: 276 – 292

Nuzzo V, (1986), Extent and status of Midwest oak savanna: Presettlement and 1985. *Natural Areas Journal*, **6**: 6 – 36

Oliver CD, Larson BC, (1996), Forest Stand Dynamics. John Wiley & Sons, Inc., New York, NY

Oliver CD, Stephens EP, (1977), Reconstruction of a mixed-species forest in central New England. *Ecology*, **58**: 562 – 572

Osmond CB, Austin MP, Berry JA, Billings WD, Boyer JS, Dacey JWH, Nobel PS, Smith SD, Winner WE, (1987), Stress physiology and the distribution of plants. *BioScience*, **37**(1): 38 – 48

Pahl-Wostl C, (1995), The dynamic nature of ecosystems: Chaos and order entwined. John Wiley & Sons Ltd., Chichester, England

Patterson WA III, (1991), The 1947 Maine fires: The last great fires in New England? Tall Timbers Fire Ecology Conference Proceedings, **17**: 59

Pickett STA, White PS, (1985), The ecology of natural disturbance and patch dynamics. Academic Press, Inc., San Diego, CA

Pyne SJ, (1982), Fire in America: A cultural history of wildland and rural fire. Princeton University Press, Princeton, NJ

Reice SR, (2001), The silver lining: The benefits of natural disasters. Princeton University Press, Princeton, NJ

Runkle JR, (1981), Gap regeneration in some old-growth forests of eastern United States. *Ecology*, **62**: 1041 – 1051

Runkle JR, (1982), Patterns of disturbance in some old-growth forests of eastern North America. *Ecology*, **63**: 1533 – 1546

Sauer CO, (1975), Man's dominance by use of fire. *Geoscience and Man*, **10**: 1 – 13

Schmidt KM, Menakis, JP, Hardy CC, Hann WJ, Bunnell, DL, (2002), Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service General Technical Report RMRS-GTR-87

Schulte LA, Crow TR, Vissage J, Cleland D, (2003), Seventy years of forest change in the Northern Great Lakes Region, USA. pp 99 – 101 in Buse LJ, Perera AH (comp.), Meeting emerging ecological, economic, and social challenges in the Great Lakes region: Popular summaries. Ontario Forest Research Information Paper No. 155, Ontario Ministry of Forest Research Institute, Sault Ste. Marie, Ontario, Canada

Seischab FK, (1990), Presettlement forests of the Phelps and Gorham Purchase in western New York. *Bulletin of the Torrey Botanical Club*, **117**: 27 – 38

Stewart OC, (1956), Fire as the first great force employed by man. pp 115 – 133 in Thomas WH (ed.), Man's role in changing the face of the earth. University of Chicago Press, Chicago, IL

Stewart, OC, (2002), Forgotten fires: Native Americans and the transient wilderness. University of Oklahoma Press, Norman, OK

Tingle JL, Klimas CV, Foti TL, (2001), Application of General Land Office Survey notes to bottomland hardwood ecosystem management and restoration in the Lower Mississippi Valley—An example from Desha County, Arkansas. pp 16 – 27 in P.B. Hamel, and T.L. Foti (eds), Bottomland hardwoods of the Mississippi Alluvial Valley: Characteristics and management of natural function, structure, and composition. USDA Forest Service General Technical Report SRS-42

Transeau EN, (1935), The prairie peninsula. *Ecology*, **16**: 423 – 437

Van Lear DH, Waldrop TA, (1989), History, uses, and effects of fire in the Appalachians. USDA Forest Service General Technical Report SE-54

Wade DD, Brock BL, Brose PH, Grace JB, Hoch GA, Patterson WA III, (2000), Fire in eastern ecosystems pp 53 – 238 (Chapter 4) in Brown JK, Smith JK (eds.), Wildland fire in ecosystems: Effects of fire on flora. USDA Forest Service General Technical Report RMRS-GTR-42-Vol. 2. (http://www.fs.fed.us/rm/pubs/rmrs_gtr42_2.pdf)

Walker J, Peet RK, (1983), Composition and species diversity of pine-wiregrass savannas of the Green Swamp, North Carolina. *Vegetatio*, **55**: 163 – 179

Watt AS, (1947), Pattern and process in the plant community. *Journal of Ecology*, **35**: 1 – 22

Wells PV, (1970), Historical factors controlling vegetation patterns and floristic distributions in the Central Plains Region of North America, pp 212 – 221 in Dort W, Jones J (eds.), Pleistocene and recent environments of the Central Great Plains. University of Kansas Special Publication No. 3, Lawrence, KS

Whitney GG, (1986), Relation of Michigan's presettlement pine forests to substrate and disturbance history. *Ecology*, **67**: 1548 – 1559

Whitney GG, DeCant JP, (2003), Physical and historical determinants of the pre- and post-settlement forests of northwestern Pennsylvania. *Canadian Journal of Forest Research*, **33**:1683 – 1697

Wright HA, Bailey AW, (1982), Fire Ecology: United States and Southern Canada. John Wiley & Sons, New York, NY

Zicker WA, (1955), An analysis of Jefferson County vegetation using survey's records and present day data. MS Thesis, University of Wisconsin-Madison